ORDNANCE MISSILE AND MUNITIONS
MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS
(28 Credit Hours)

INTRODUCTION

The announcement of the first transistor in June 1948 brought about many revolutionary changes in the field of electronics. Compared to the then conventional vacuum tube, the transistor has a much higher operating efficiency and is much smaller in size. Being a solid-state device, neither a special envelope to house a vacuum nor special heating elements to provide electrons is required. The latter fact alone represents a considerable saving in power since, in most standard receiving tubes, as much or more power is expended in heating the filament as in drawing current through the tubes.

Although the transistor serves mainly as a replacement for the vacuum tube, it is not enough to think of it in such limited terms. Because it is a solid-state semiconductor, it has patterns of electron flow quite different from the conventional electron tube. It is important for anyone associated with the field of electronics to understand these patterns and know the general advantages and limitations of the transistor.

Semiconductor devices, as the transistor, are finding widespread application in such modern missile systems as the Lance, Pershing, TOW, and Hawk. Since all of these systems require the use of amplifiers, oscillators, detectors, multivibrators, and countless other circuits, it is important to develop a basic knowledge of the application of the transistor and semiconductor in these types of circuits.

This subcourse consists of the theory and application of transistors and semiconductors in power supplies, amplifiers, oscillators, timing circuits and modulation and demodulation circuits. Special purpose semiconductor devices are also covered in this subcourse.

The skills and knowledge taught in this subcourse are common to all missile repairer tasks.

This subcourse consists of nine lessons and examination as follows:

Lesson 1	Introduction to Transistors and Semiconductors	1 hour
Lesson 2	Theory of Transistors and Semiconductors	3 hours
Lesson 3	Semiconductor Diode Rectifiers and Transistor Amplifier Fundamentals	3 hours
Lesson 4	Bias Stabilization	2 hours
Lesson 5	Transistor Amplifiers	3 hours
Lesson 6	Oscillators and Multivibrators	4 hours
Lesson 7	Triggered and Gating Circuits	4 hours
Lesson 8	Modulation and Demodulation	2 hours
Lesson 9	Special Purpose Semiconductor Devices	3 hours
Examination		3 hours

PREFACE

The Army Institute for Professional Development (AIPD) administers the consolidated Army Correspondence Course Program (ACCP), which provides high-quality, economical training to its users. The AIPD is accredited by the Accrediting Commission of the Distance Education and Training Council (DETC), the nationally recognized accrediting agency for correspondence institutions.

Accreditation is a process that gives public recognition to educational institutions, which meet published standards of quality. The DETC has developed a thorough and careful evaluation system to assure that institutions meet standards of academic and administrative excellence before it awards accreditation.

The many TRADOC service schools and DOD agencies that produce the ACCP materials administered by the AIPD develop them to the DETC standards.

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LESSON 1. INTRODUCTION TO TRANSISTORS AND SEMICONDUCTORS

MMS Subcourse Number 701.....	**Transistors and Semiconductors**
Lesson Objective.....	**To introduce the student to transistors and semiconductors to include history, functions and construction.**
Credit Hours.....	**One**

TEXT

1. GENERAL. Fundamentally, a semiconductor device is a valve that controls the flow of current carriers (electrical charges in motion) through the crystal material of which it is made. A transistor's ability to control current carriers makes it potentially the most useful single element in modern electronic equipment. Transistors are used in military radio, sound, radar, telephone, missile circuitry and computers.

2. HISTORY.

a. Crystal Rectifier. The first use of a crystal semiconductor (figure 1-1) as a rectifier (detector) was in the early days of radio. A crystal was clamped in a small cup or receptacle and a flexible wire (cat-whisker) made light contact with the crystal. The receiver was tuned by operating the adjusting arm until the cat-whisker was positioned on a spot of the crystal that resulted in a sound in the headset. Tuning the variable capacitor provided maximum signal in the headset; frequent adjustment of the contact point was required.

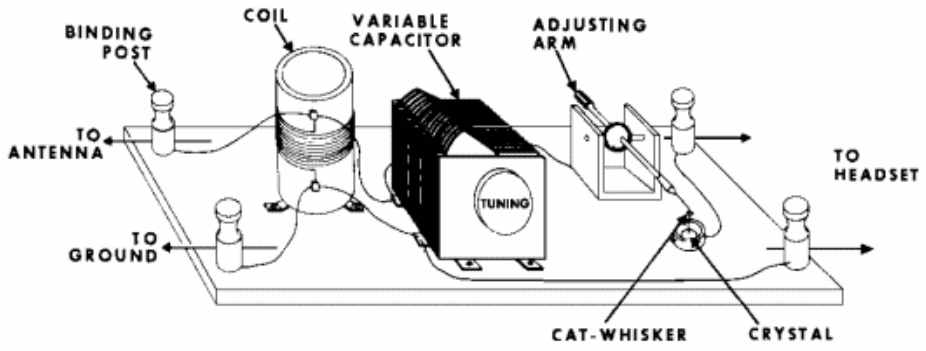


Figure 1-1. Radio receiver using crystal rectifier.

b. Point Contact Diode. Point contact diodes (figure 1-2) (germanium rectifiers) were used during World War II to replace electron tubes in radar and other high frequency equipment. The point contact diode has a very low shunt capacitance and does not require heater power. These properties are definite advantages over the electron tube diode. The point contact diode is identical with the crystal rectifier in that it includes a semiconductor, a metal base, and a metallic point contact. The connections to the point contact diode are an external lead welded to the metallic point contact, and an external lead welded to the metal base.

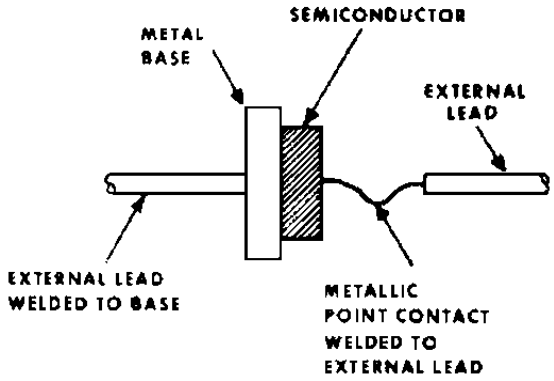


Figure 1-2. Physical construction of point contact diode.

c. Point Contact Transistor. The point contact transistor (figure 1-3) was developed in 1948. The physical construction of the point contact transistor is similar to that of the point contact diode except that a third lead with a metallic point contact is placed near the other metallic point contact on the semiconductor. One lead is called an emitter lead the other, a collector lead. When appropriate voltages are applied to the two metallic points (proper bias with respect to the metal base) the point contact transistor is capable of producing a power gain.

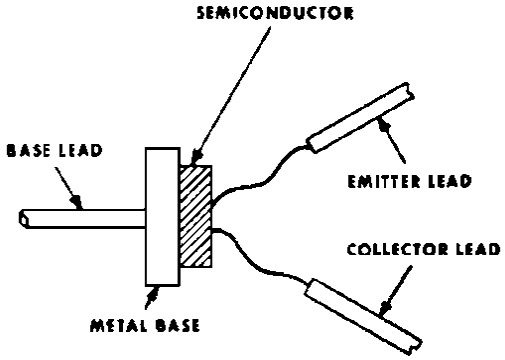


Figure 1-3. Physical construction of point contact transistor.

d. Junction Diode. The junction diode (figure 1-4), developed in 1949, consists of a junction between two dissimilar sections of semiconductor material. One section, because of its characteristics, is called a P-type semiconductor the other, an N-type semiconductor. The connections to the junction diode consists of one lead to the P-type and one lead to the N-type semiconductor materials. The junction diode can handle more power than the point contact diode but it also has a larger shunt capacitance.

e. Junction Transistor. The junction transistor was developed about the same time as the junction diode in 1949. The junction transistor consists of two PN junctions (A and B, figure 1-5). Operation of the junction transistor is similar to that of the point contact transistor. The junction transistor however, permits more accurate prediction of circuit performance, has a lower signal-to-noise ratio, and can handle more power than the point contact transistor.

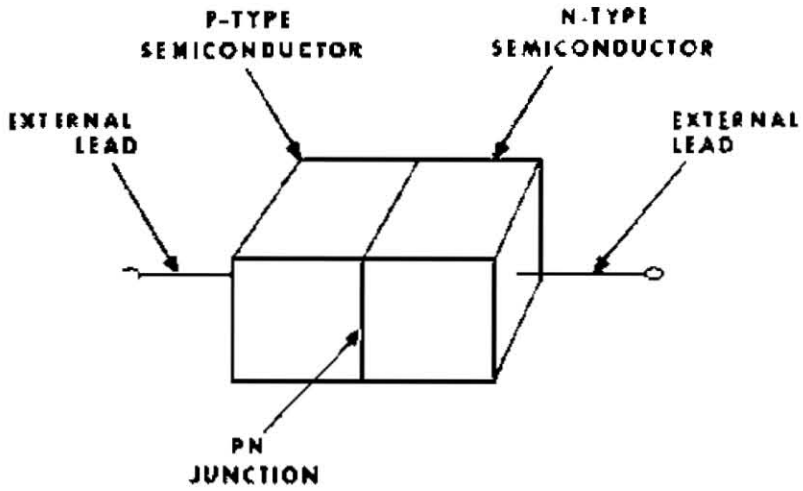


Figure 1-4. Physical construction of junction diode.

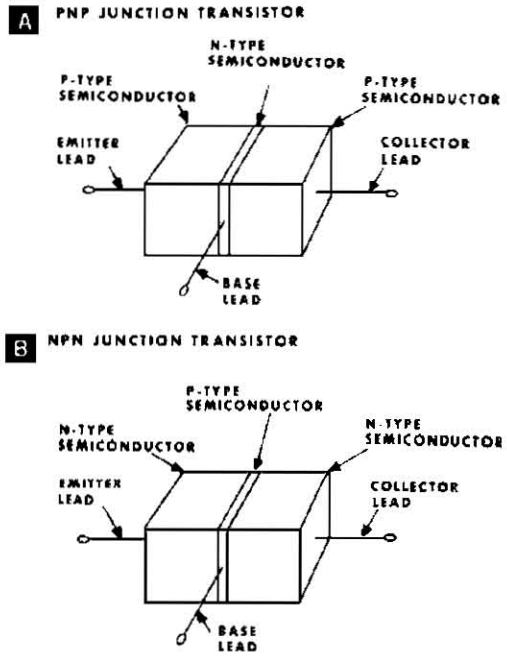


Figure 1-5. Physical construction of PNP and NPN junction transistors.

3. TRANSISTOR FUNCTIONS.

a. Amplification. The transistor may be used as a current, voltage, or power amplifier. For instance, a stronger signal current may be obtained from a transistor (A, figure 1-6) than is fed into it. A signal of 1 milliampere fed into the input circuit of the transistor may be amplified to 20 milliamperes at its output. The amount of amplification depends on how the circuit is designed.

b. Oscillation. The transistor can be used in an oscillator circuit because it can convert direct current energy into alternating current energy. When it is connected in an oscillator circuit, the transistor draws energy from a dc source and generates a dc voltage changing at an ac rate (B, figure 1-6).

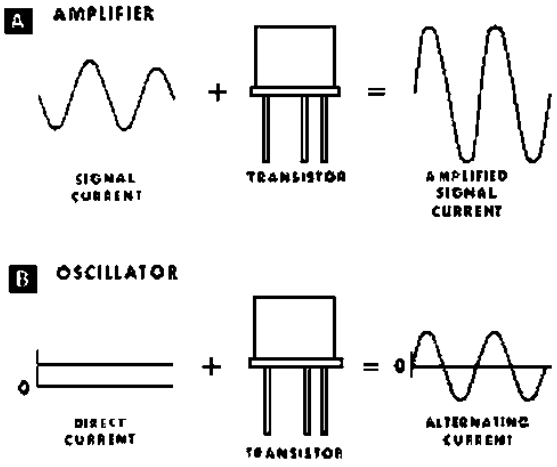


Figure 1-6. Transistor used as amplifier or oscillator.

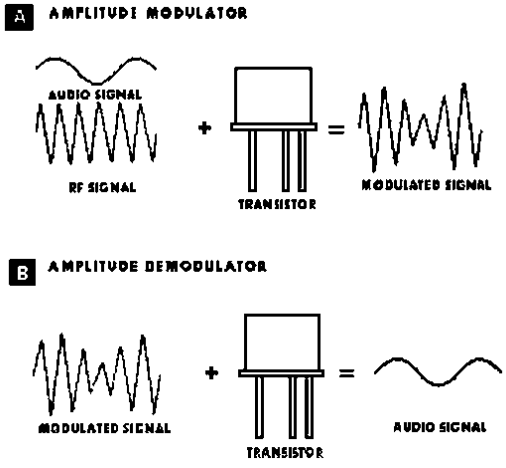


Figure 1-7. Transistor used as (AM) modulator or (AM) demodulator.

c. Modulation and Demodulation. The transistor can be used in circuits that provide amplitude modulation (variation in amplitude of an RF signal) (A, figure 1-7) or frequency modulation (variation in frequency of an RF signal) (A, figure 1-8). Conversely, demodulation or detection of amplitude modulated signals (B, figure 1-7) and frequency modulated signals (B, figure 1-8) can also be accomplished with transistors. These circuits are well suited for miniature transmitters intended for short range applications.

d. Miscellaneous. The transistor may also be used to change the shape of signal waveforms. Waveform shaping is vital in various types of radar, teletypewriter, computer, and television circuits. A, figure 1-9, shows how a transistor can be used in a circuit to change a sine wave into a square wave. B of the figure shows how a transistor can be used in a circuit to remove the negative or positive alterations of a series of positive and negative pulses.

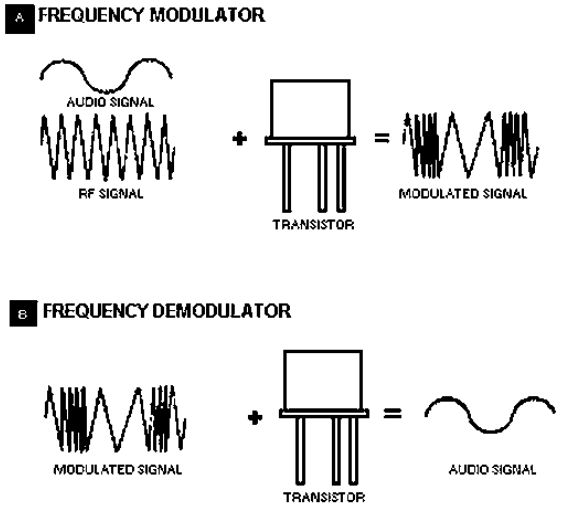


Figure 1-8. Transistor used as (FM) modulator or (FM) demodulator.

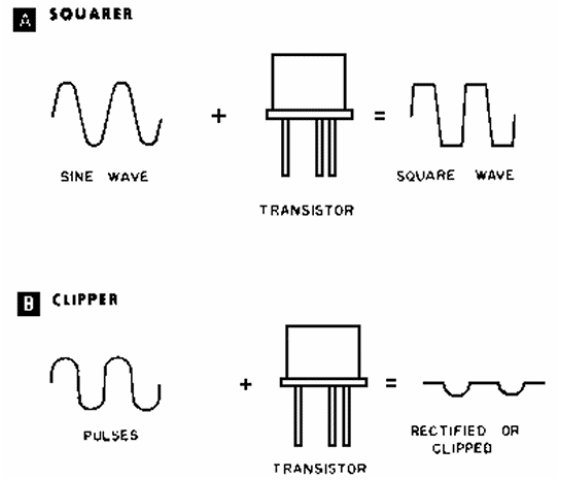


Figure 1-9. Transistor used to change waveforms.

4. USE IN MILITARY AND COMMERCIAL EQUIPMENTS.

a. Portable Equipment. The use of transistors opened an entirely new field in the development of portable equipment. The compactness and ruggedness of transistorized equipment permits its application in a variety of portable equipments. Transistors are now being used in mobile equipment, test equipment, tape recordings, meteorological equipment, and photographic equipment. Various portable equipments in commercial use, such as tape recorders, radios, television sets, hearing aids, automobile radios, and marine radios now employ transistors.

b. Fixed Equipments. Fixed equipments that use semiconductor devices take up less space, and use less power. Military and commercial equipment such as wire systems (telephone or teletypewriter), facsimile, radar, computers, public address systems, intercommunications systems, television and radio receivers and transmitters use transistorized (semiconductor) circuitry.

5. COMPARISON WITH ELECTRON TUBES.

a. Efficiency and Voltage Requirements. The transistor power efficiency is greater than that of the electron tube because the transistor does not require heater power. In addition, it does not require warm-up time, and it does not require a high dc voltage to operate. Other advantages of the transistor are its useful life (b below), its noise level (c below), and its size and construction.

b. Useful Life. Life expectancy is a very important consideration in the application of any electronic device. A transistor that is hermetically sealed in glass or metal will withstand a variety of situations that an electron tube cannot withstand. For example, a transistor, even though it is immersed in water, will operate for long periods of time with very little noticeable effect on its operating frequency. It also will withstand centrifugal force gravity and impact tests that would completely shatter an electron tube. Although transistors are a comparatively new development, it has been estimated that they can operate continuously for approximately 8 years.

c. Noise Level. Noise, in this case, is an audible or observable disturbance caused by the random motion of electronis within the transistor and its associated parts. The noise level of a transistor at low frequencies (about 1000 Hz) is better than the noise level of an electron tube. When a transistor is used at higher frequencies, its noise level becomes considerably lower.

d. Size and Construction. Electron tubes are designed to permit efficient dissipation of heat. They are much larger than transistors. Although transistors must also dissipate heat, the amount is very small. The flange type construction of the transistor cover provides heat dissipation. In some cases a special metallic heat dissipater must also be used on a transistor.

6. TRANSISTOR MATERIAL. Materials such as copper, silver, gold, and iron, which provide a good path for electron flow with little opposition (resistance), are classified as conductors. On the other hand, materials such as rubber, porcelain, and glass, which offer great opposition and do not provide a path for electron flow, are insulators. In between these two classifications are materials such as carbon in diamond form, germanium, and silicon - the semiconductors. Semiconductors provide a path for electron flow but offer moderate opposition to it. Transistors are usually made of semiconductor material, such as germanium or silicon.

7. MINIATURE PARTS CAN BE USED WITH TRANSISTORS. One of the persistent problems with equipment that uses electron tubes is size. Compared with transistors, electron tubes are relatively large. They require high current and voltage to operate and the circuit parts used with them have to be large also. In contrast, the current and voltage used to operate transistors is very low. The circuit parts used with transistors may be very small. Miniature capacitors, resistors, coils and transformers may be used. In addition, printed circuit boards are used to eliminate (as much as possible) connecting wires and to make equipment more compact.

MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS

EXERCISES FOR LESSON 1

1. A semiconductor may be explained as a device that controls electrical charges in motion by acting as a

   A. amplifier.
   B. valve.
   C. pipe.
   D. limiter.

2. What is the first known use of a semiconductor?

   A. Junction diode
   B. Point contact transistor
   C. Crystal rectifier
   D. Point contact diode

3. The point contact diode

   A. has a very low shunt capacitance.
   B. requires heater power.
   C. has a high shunt capacitance.
   D. does not have an external lead.

4. What is another name for the point contact diode?

   A. AM modulator
   B. Crystal rectifier
   C. P-type semiconductor
   D. Germanium rectifier

5. In comparing the junction transistor with a junction diode, the junction transistor

   A. cannot handle as much power.
   B. has a lower signal-to-noise ratio.
   C. has a greater signal-to-noise ratio.
   D. has one PN junction.

6. Which is NOT a function of a transistor?

   A. Oscillation
   B. Waveform shaping
   C. Divider
   D. Modulation and demodulation

7. Which is a semiconductor material?

   A. Copper
   B. Germanium
   C. Porcelain
   D. Gold

8. Transistors are an improvement over vacuum tubes because of

   A. ruggedness.
   B. compactness.
   C. durability.
   D. all of the above.

9. How does the noise level of a transistor used at high frequencies compare with a transistor used at low frequencies?

   A. Lower
   B. Higher
   C. Same
   D. About double

10. When comparing transistor operation with tube operation, which is true?

   A. Higher current and voltages are needed
   B. May be operated with smaller circuit parts
   C. Transistors require more connecting wires
   D. Transistors generate more heat

LESSON 2. THEORY OF TRANSISTORS AND SEMICONDUCTORS

MMS Subcourse Number 701.....	**Transistors and Semiconductors**
Lesson Objective.....	**To introduce the student to transistors and Semiconductors to include description, construction, and theory of operation.**
Credit Hours.....	**Three**

TEXT

1. CRYSTALS, DONORS, ACCEPTORS, AND HOLES.

a. General. In order to examine and discuss the theory of semiconductors, it is necessary to consider the nature of crystals. Most solids, except those that have a biological structure of cells such as the leaves of trees and bones, have a crystal structure. In fact, many substances can be seen to have a specific crystal pattern when viewed through a microscope. They can be identified by the angles and planes of their surface areas: some crystal materials form as cubes; and some form as long needles and variations of hexagonal structures. When a semiconductor device is examined it is not possible to see the crystal. Therefore, the atomic structure of selected crystals will be discussed in order to better understand how semiconductors work.

b. Atomic Structure and Valence Electrons.

(1) Atomic structure. To begin the discussion of semiconductors it is necessary to look at the atomic structure of germanium, silicon, aluminum, and phosphorous.

NOTE In this discussion only the interaction of electrons and protons will be covered. Other particles within the atom are of no importance in this explanation.

(a) Germanium atom. Part A of figure 2-1 shows that the nucleus or core of the atom contains 32 protons or positive particles; it also has 41 neutrons or neutral particles. Notice, also, that there are 32 electrons or negative particles that travel around the nucleus in four rings (shells).

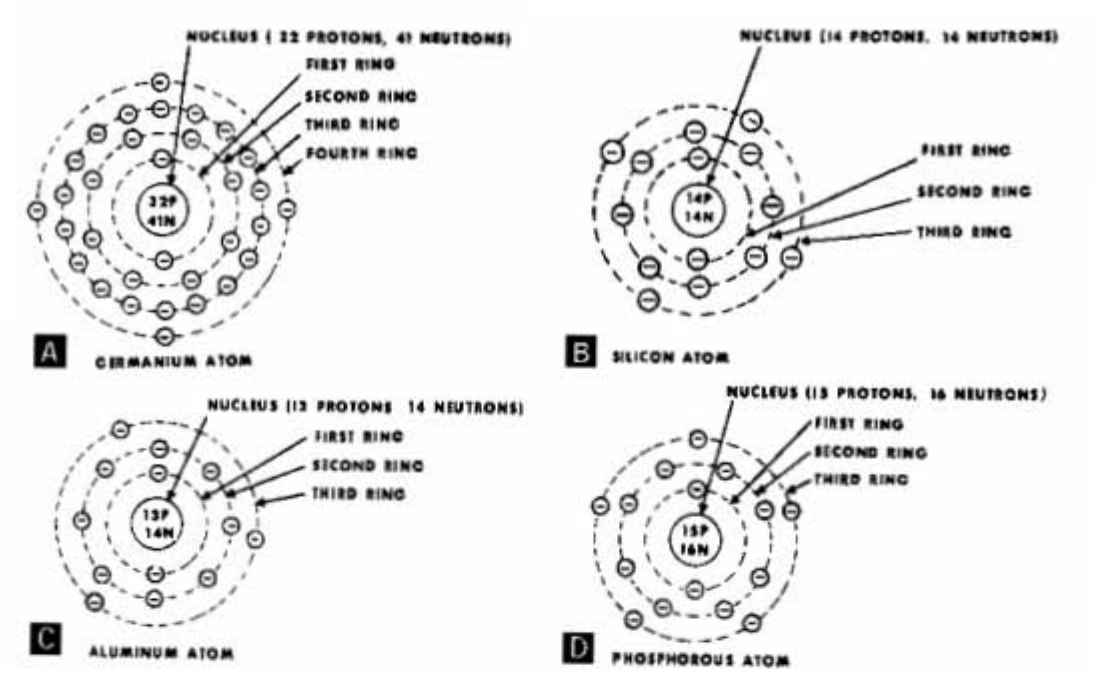


Figure 2-1. Structure of atoms.

1. In its normal state the atom is electrically neutral; the number of negative particles (electrons) equals the number of positive particles (protons). The inner three rings are complete with a total of 28 tightly bound electrons. The outer ring is incomplete and has only four electrons. These electrons in the outer ring are called valence electrons; they are free to move around within the crystal structure.

2. The outer ring of a single germanium atom is incomplete with only four electrons. Its outer ring would be complete with eight electrons. The problem therefore, is to increase the number of electrons in the outer ring.

3. The solution is to allow the single atom to share its valence electrons with other adjacent atoms. Fortunately, the valence electrons attempt to pair off with those of another atom to complete the outer shell. When this happens and atoms are bound together through their valence electrons, it is called an electron-pair bond. A more common term for atoms sharing electrons in this manner is covalent bonding.

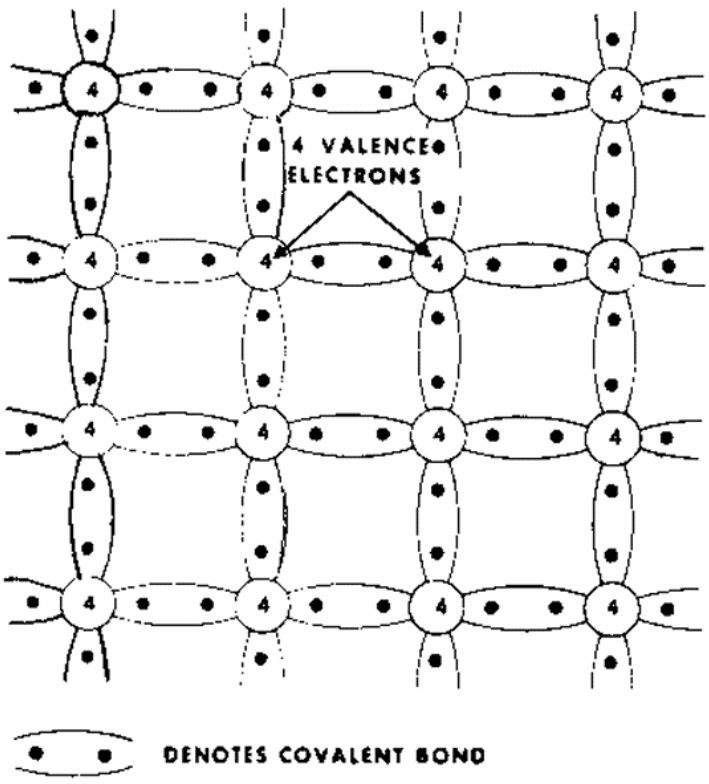


Figure 2-2. Covalent bond structure of a perfect germanium or silicon crystal.

4. Figure 2-2 shows the covalent bonding of adjacent atoms, here each atom shares its valence electrons. The number four within the nucleus indicates the number of electrons in the outer ring. Note that this discussion is really about the valence electrons only, and the other electrons on the inner rings of the atoms are of little concern.

(b) Silicon atom. The silicon atom contains 14 electrons (B, figure 2-1). The similarity between a germanium atom and a silicon atom is that they both have four valence electrons. Semiconductor devices and transistors may be made from either germanium or silicon crystals.

(c) Aluminum atoms. Notice that there are 13 electrons in orbit (C, figure 2-1). This atom contains three valence electrons.

(d) Phosphorous atoms (D, figure 2-1). Similar to the other atoms that have been covered, its outer ring is also incomplete. A phosphorous atom contains 5 valence electrons.

(2) Valence electrons. The valence electrons in each atom of a good conductor, such as copper, are loosely bound to the nucleus. Under the influence of an electric field, they move easily through the conductor. However, valence electrons that are part of a covalent bond do not readily break away from their bonds. That is why crystal materials such as germanium and silicon are poor conductors under normal conditions.

c. Electron Flow in Semiconductors. So far, only the atomic structure of semiconductors that are not influenced by any outside force such as heat or light, have been analyzed. Without heat or light, all of the electrons are held in their orbits they are not able to break away to move within the crystal material. Therefore, semiconductors at low temperatures are not exposed to any other outside force are actually nonconductors.

(1) At room temperature there is enough heat (thermal energy) to cause the semiconductor crystals to vibrate and shake loose some electrons from their covalent bonds. The few electrons set loose are free to move or drift aimlessly throughout the semiconductor crystal; they are called free electrons.

(2) After an electron breaks away from its covalent bond, the atom it leaves is then missing one electron. The result is that when the atom loses one electron, it contains more protons (positive charges) than electrons (negative charges). That particular atom is positively charged. But remember that the free electron is still within the crystal material so that the total number of protons and electrons in the crystal still balance each other. As far as the overall piece of semiconductor material is concerned, it is still electrically neutral.

d. Electron-Hole Theory. Under certain conditions, then, electrons may break away from their orbits. The loss of an electron in the outer ring of an atom leaves a hole in the ring and makes them positively charged. This positive atom may now attract an electron from another atom. When an electron from another atom fills the hole of the positively charged atom, we can say that the first atom is now neutral and the second atom is now a positively charged atom.

(1) As electrons travel from one atom to another, they fill the holes in some atoms and leave holes in other atoms. Basically, two things are occurring: electrons are moving in one direction and holes are moving in the opposite direction.

(2) In A, figure 2-3, an electron leaves atom "A", making it a positively charged atom. An electron from atom "E" breaks away and fills the first hole leaving the second atom with a hole.

(3) In B, figure 2-3, the hole has moved from atom "A" to atom "E". An electron leaving atom "B" will fill the hole in atom "E".

(4) In C, figure 2-3, an electron from atom "C" will fill the hole in atom "B", neutralizing that atom and leaving a hole in atom "C".

(5) D and E, figure 2-3, show additional hole and electron movement between atom "C" and atom "H".

(6) Notice that the movement of holes is opposite to the direction of the movement of the electrons. The crystal material is still electrically neutral, and there is one free electron at one end of the crystal and one hole at the other end (F, figure 2-3).

e. Impurities.

(1) General. It is possible for atoms of elements, other than germanium and silicon, to join the crystal structure. These elements are added intentionally during the processing of germanium or silicon and are referred to as impurities.

(2) Donor and acceptor impurities. Two groups of elements can be added to the crystal structure of either germanium or silicon. The elements in one group are called donors; in the second group they are called acceptors.

(a) A donor element or atom is classified as such because it has five valence electrons. Common donor elements are arsenic, phosphorous, and antimony (A, figure 2-4). When a donor atom is compared with a germanium or silicon atom, an additional valence electron is found (A and B, figure 2-4).

(b) An acceptor element contains only three valence electrons. Aluminum, boron, gallium and indium are types of acceptor atoms (C, figure 2-4). When the acceptor atom is compared with either germanium or silicon, one less valence atom is found. This missing atom is then referred to as a hole (B and C, figure 2-4).

f. N-type Semiconductor Materials use Donor Impurities.

(1) Figure 2-5 shows a semiconductor crystal in which one of the semiconductor atoms has been replaced by a donor atom. The donor impurity contains five valence electrons. Note that four of the valence electrons form a covalent bond with electrons of four of its neighbors. The electrons of the semiconductor atoms and donor atoms that enter into the covalent bonds form very stable structures and are not readily displaced.

(2) The fifth valence electron of the donor atom cannot form a covalent bond and the nucleus of the donor atom has a very weak influence over this excess electron. The excess electron, therefore, is mobile and is called a free electron. At normal room temperature, enough thermal or heat energy is present to cause this excess electron to break away from the donor and drift through the crystal structure. The result is that for each donor atom, we obtain what may be considered one free electron.

(3) Germanium or silicon material containing donor impurities is referred to as N-type material. The letter N refers to the negative charge of the excess or free electrons. Impurities are added to N-type semiconductor material in the proportion of one atom to several million semiconductor (germanium, silicon) atoms.

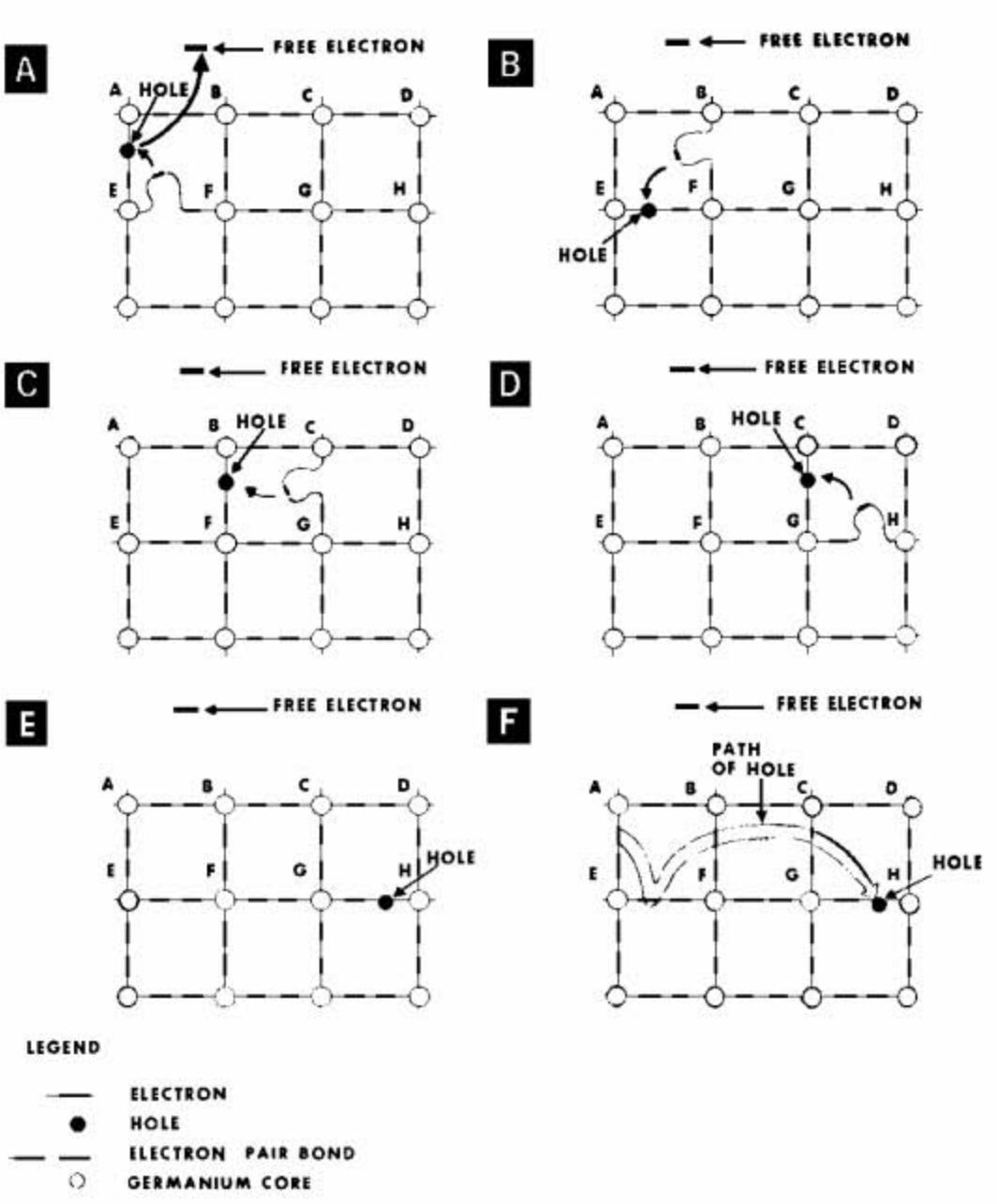


Figure 2-3. Movement of hole through crystal.

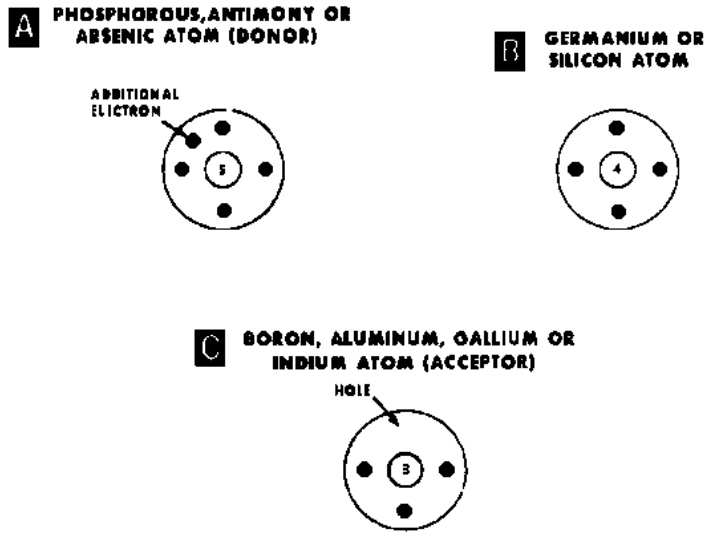


Figure 2-4. Comparing the valence of several atoms.

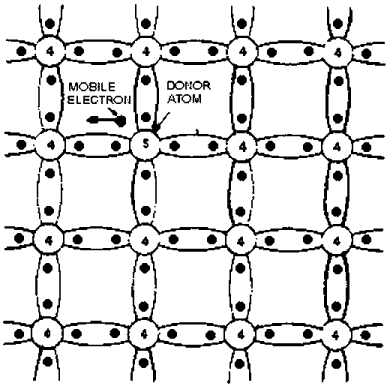


Figure 2-5. Semiconductor crystal with a donor atom.

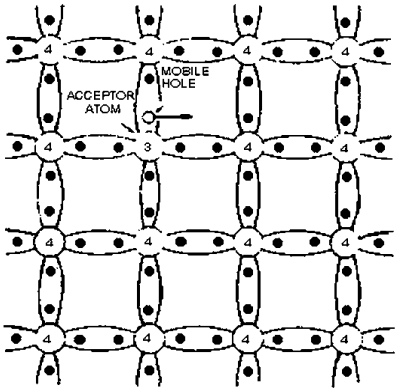


Figure 2-6. Semiconductor crystal with an acceptor atom.

(4) After the excess or free electron leaves the donor atom, the donor atom has a positive charge. This positive charge is balanced in the crystal structure by the negative charge of the free electron. Remember that an atom that either gains or loses an electron is called an ion.

(5) Note that the semiconductor material that contains a donor ion (positive) will also contain a free electron (negative). The crystal material taken as a whole, therefore, is electrically neutral: it has a net charge of zero.

g. P-type Semiconductor Materials Use Acceptor Materials.

(1) Figure 2-6 shows a semiconductor crystal in which one of the semiconductor atoms has been replaced by an acceptor atom. The acceptor impurity contains three valence electrons that form covalent bonds with electrons of neighboring atoms.

(2) One valence electron of the fourth neighboring semiconductor atom cannot form a covalent bond because the acceptor has only three valence electrons. The position that would normally be filled with an electron is designated a hole.

(3) It is possible for an electron from an adjacent covalent bond to absorb enough energy to break its bond and fill the hole. When this happens, the hole moves to a new position and two important changes take place.

(a) The first change is that the acceptor atom is ionized. The acceptor has acquired (or accepted) an electron and is now a negative ion.

(b) The second change is that the semiconductor atom, which requires four valence electrons, is left with only three valence electrons. The semiconductor atom, lacking an electron, has a net positive charge equivalent to the negative charge of the electron. The positive hole moves within the crystal in the same manner that a free electron moves within the crystal. The concept of holes and their movement is very important in understanding the operation of transistors.

(4) Note that the semiconductor crystal that contains an acceptor ion (negative) also contains a hole (positive). The entire semiconductor crystal therefore, has a net charge of zero.

(5) Germanium or silicon crystals containing acceptor impurities are referred to as P-type material. The letter "P" refers to the positive charge of the hole.

h. Electrons and Holes as Current Carriers. When a voltage is applied across a semiconductor, conduction occurs by electron and hole movements. Electrons (negative charges) are attracted by the positive voltage and repelled by the negative voltage. Holes (positive charges) move in the opposite direction from the electrons. Holes are attracted by the negative voltage and are repelled by the positive voltage (A, figure 2-7).

(1) Electrons are attracted to the positive terminal of the battery (B, figure 2-7). For every electron that leaves the crystal, another electron enters it from the negative terminal of the battery.

(2) When an electron leaves the crystal it leaves a hole behind (C, figure 2-7). The holes left behind and all other holes in the crystal are attracted to the negative terminal (D, figure 2-7).

(3) Notice that holes do not flow into the battery but move only inside the crystal. As the holes arrive at the negative terminal they combine with the incoming electrons. For every electron that leaves the crystal, another electron enters and fills the hole that it leaves behind.

(4) If we reverse the battery across a single piece of either N- or P-type material, the amount of current will remain the same. Electrons will still move towards the positive battery terminals and holes will move towards the negative battery terminal. Reversing the battery in figure 2-7 will only reverse the direction of movement of the electrons and holes.

i. Majority and Minority Current Carriers.

(1) N-type semiconductor material. The process of adding impurities to a semiconductor is called doping and N-type material has many free electrons as a result of doping. A, figure 2-8, shows N-type material containing many free electrons and a few holes. Holes exist in the N-type material due to the breaking away of valence electrons when the material is subjected to heat, light, or an applied voltage.

(a) The dashed lines indicate the formation of a hole and the valence electron that produced the hole. If the holes and the valence electrons within the dashed lines were recombined, only the free electrons from the donor atoms would be present.

(b) B, figure 2-8, shows the same charges except that electrons are shown as negative particles and holes as positive particles. If the number of positive holes and negative electrons are counted, it will show many more electrons than holes.

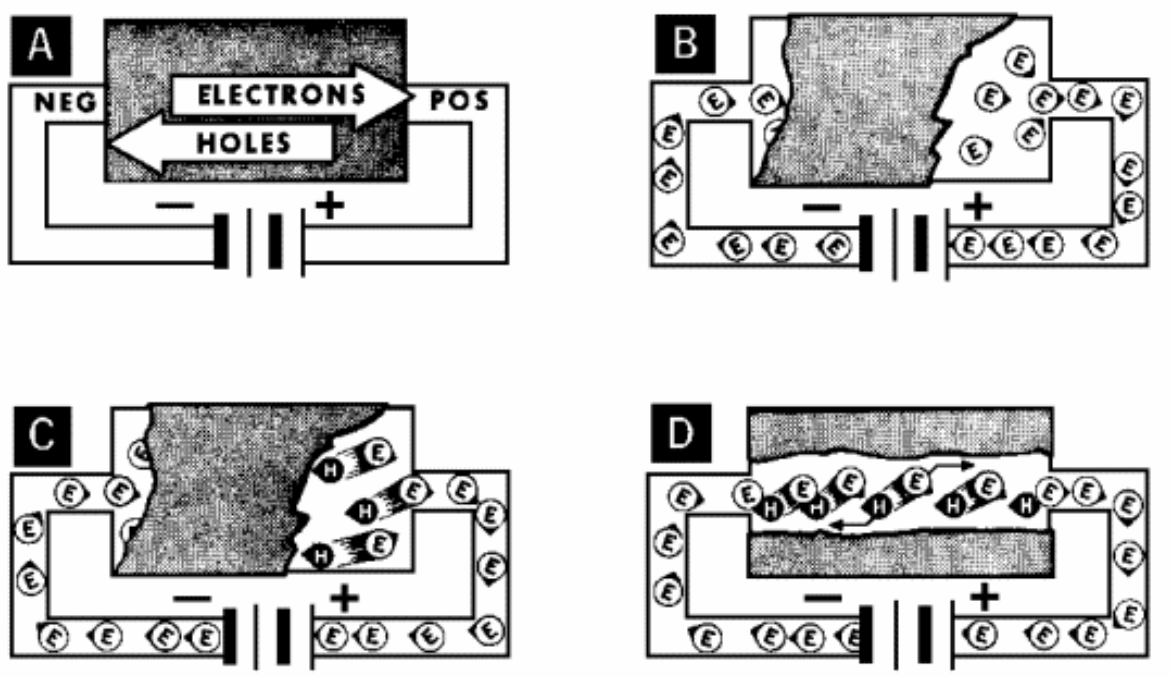


Figure 2-7. Conduction in N- or P-type semiconductor material.

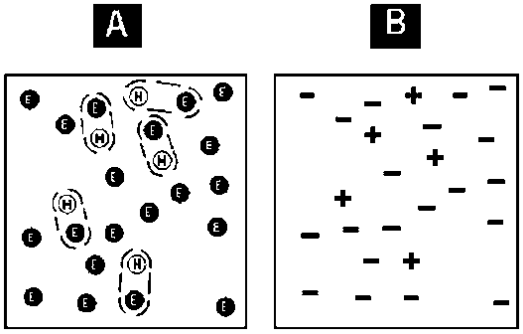


Figure 2-8. N-type semiconductor.

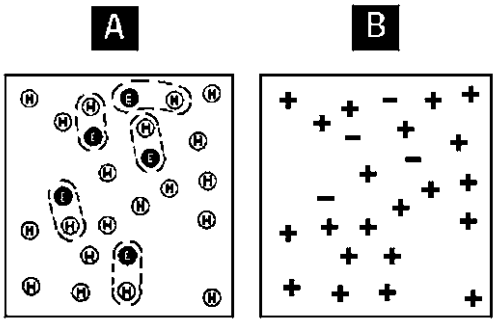


Figure 2-9. P-type semiconductor.

(c) When a voltage is applied to the N-type material, most of the current within the crystal is caused by the movement of electrons. Electrons are the majority current carriers in N-type material. Some holes, however, also cause a small current; they are the minority current carriers.

(2) P-type semiconductor material. As a result of doping (addition of acceptor atoms), P-type material contains many free holes. A, figure 2-9, shows the holes and also electron and hole combinations (within the dashed lines) formed by electrons breaking their covalent bonds. The holes and electrons in the same material are shown as negative and positive charges in B of figure 2-9.

(a) When a voltage is applied to the P-type material, more holes move than electrons because it contains more holes.

(b) Thus, the majority current carriers in P-type material are holes; the minority current carriers are electrons.

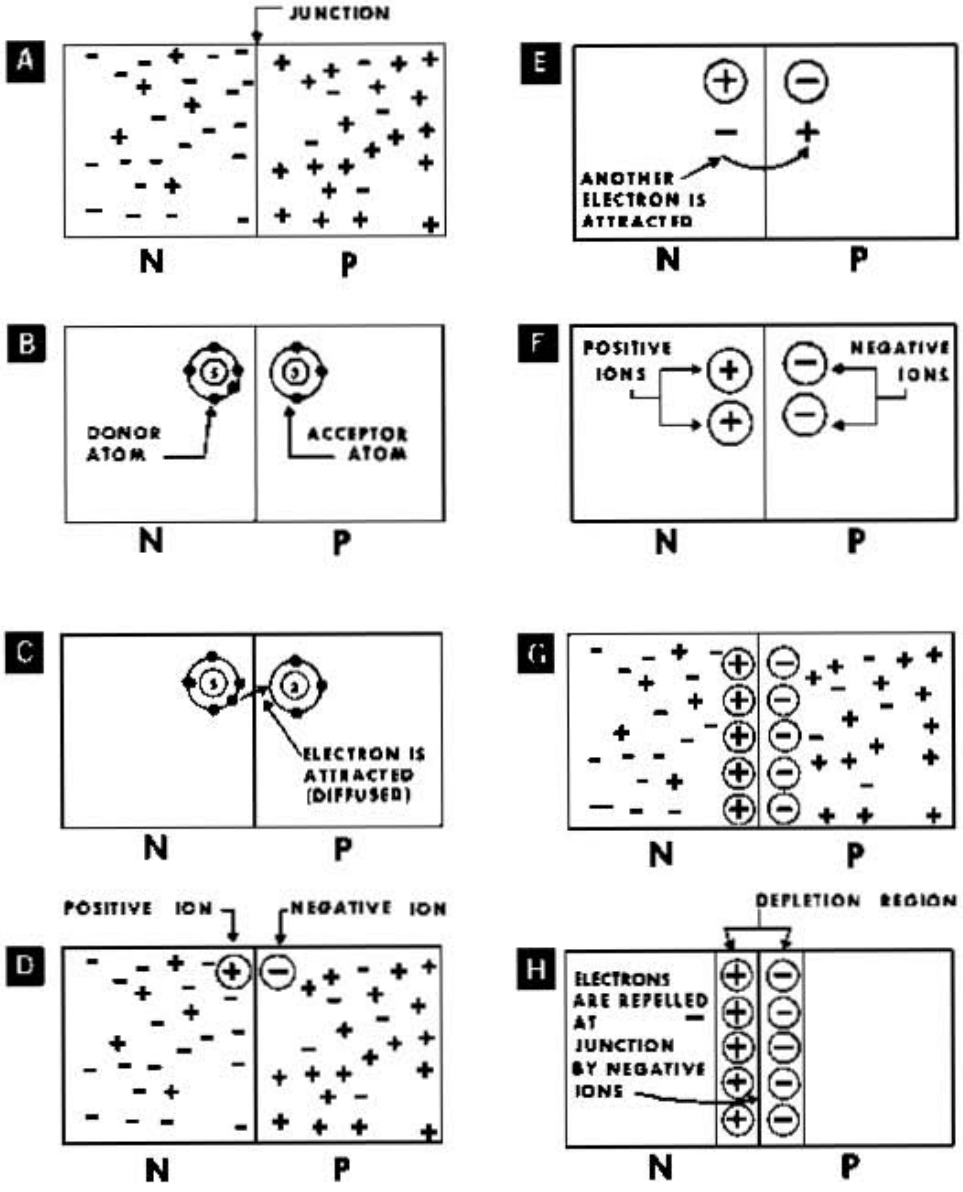


Figure 2-10. PN junction.

2. PN JUNCTIONS.

a. PN Junction Fundamentals. When two small pieces of N-type and P-type germanium or silicon are brought together, their contacting surfaces are called a PN junction. An unusual and very important action occurs at the PN junction. This action at the junction ((1) through (6) below) permits the semiconductors to duplicate the operation of most electron tubes.

(1) In A, figure 2-10, a piece of N-type material and a piece of P-type material are shown joined. The surface areas of the materials in contact with each other is called the junction, hence the name PN junction. Note that in figure 2-10 there are no external circuits or voltages connected to the semiconductor material.

(2) Within each piece of semiconductor material, there is a constant movement of electrons and holes due to thermal energy. This movement in the absence of an applied electrical field is called diffusion. Looking at the two pieces of material that were joined, we might expect all the electrons in the N-type material to cross the junction and combine with all of the holes in the P-type material. And some electrons do cross the junction. But when they do, they produce a depletion region. A depletion region is the region that occurs at the PN junction caused by the formation of negative and positive ions. The depletion region prevents the free electrons in the N-type material from combining with the free holes in the P-type material.

(3) B and C, figure 2-10, shows that at the junction, the free electron of the donor atom diffuses (moves) toward the hole in the acceptor atom and combines with the hole. After it loses an electron, the donor atom becomes a positive ion (positively charged particle). Also, the acceptor atom gains an electron and becomes a negative ion (negatively charged particle). D, figure 2-10, shows the positive ion produced in the N material and the negative ion produced in the P material.

(4) E and F, figure 2-10, shows a second electron in the N material combining with a hole in the P material, producing another set of positive and negative ions. This action will continue for a short time in the immediate vicinity of the junction until a number of positive and negative ions form on both sides of the junction (G, figure 2-10). This area at the junction is called the depletion region. The number of ions in the depletion region remains fixed; they do not contribute to current through the semiconductor.

(5) After the depletion region is formed, any additional electrons that try to move across the junction are repelled by the negative ions now present in the P material (H, figure 2-10). As a result, further recombination of electrons and holes across the junction cannot occur.

(6) The charged atoms or ions within the depletion region produce the same effect as connecting a tiny battery across the PN junction. In effect, the positive terminal of the "battery" is connected to the N material and its negative terminal to the P material (figure 2-11). That's why the voltage developed across the depletion region is called a potential barrier. The physical width of the depletion region is very narrow and, with germanium, it produces only a very weak potential barrier, approximately 0.1 volt. Silicon requires 600 mV.

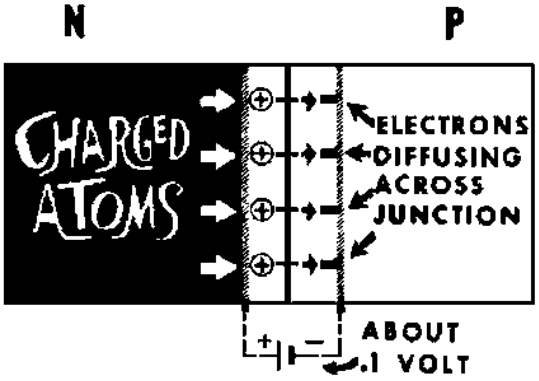


Figure 2-11. Potential barrier across depletion region.

b. PN Junction Basic Diode Operation. A diode is the simplest form of a semiconductor device and contains two elements (cathode and anode). A semiconductor diode circuit is easily constructed by connecting a battery across the P- and N-type semiconductor materials. By connecting the positive terminal of the battery to the P material and the negative battery terminal to the N material, we cause a current to flow (A, figure 2-12). This method of connecting PN diodes is called forward bias. Bias is the dc voltage existing between two points such as the cathode and anode of a diode or between the base and emitter of a transistor. Bias is usually developed by a bias voltage. The total bias voltage is equal to the bias battery voltage plus the applied signal voltage. Forward bias occurs when a battery is connected across a semiconductor diode so that a large current flows. Reversing the polarity of the battery (B, figure 2-12) allows so little current to flow that the amount is negligible. This method of connecting PN diodes is called reverse bias.

c. PN Junction, Forward Bias.

(1) When an external battery is connected to a PN junction as shown in figure 2-13, current will flow. Electrons in the N material are repelled by the negative terminal of the battery and move towards the junction. Holes in the P material are repelled by the positive terminal of the battery and move towards the junction. Because of their acquired energy caused by the battery, many of the holes and free electrons are able to penetrate the depletion region and combine with their counterparts in the opposite type of material.

(2) For each electron that crosses the junction and combines with a hole in the P material, an electron enters the N material from the negative terminal of the battery. Each electron that enters the N material moves towards the junction. Similarly, an electron from a covalent bond in the P material, near the positive battery terminal, will break its bond and enter the positive battery terminal. For each electron that breaks its bond, a hole is created which moves towards the junction. Recombination (electrons filling holes) in and about the depletion region continues as long as the external battery is connected.

(3) The current in the P material consists of holes. When this condition is achieved, the PN junction is said to biased in the forward direction. There is a continuous electron current in the external circuit and if the forward bias is increased (battery voltage increased), the current will increase.

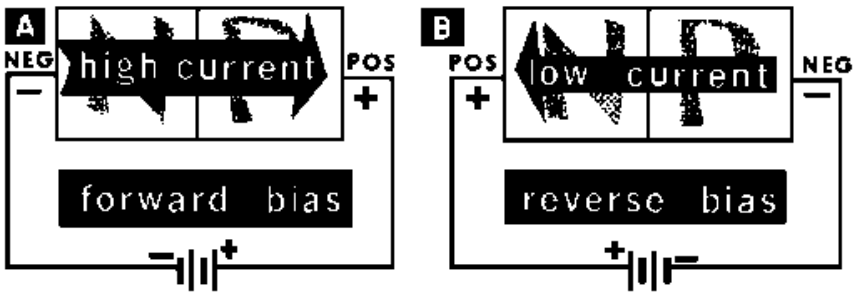


Figure 2-12. Forward and reverse biased diodes.

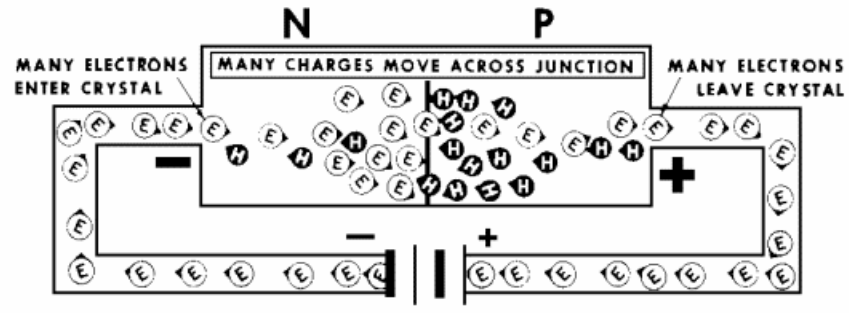


Figure 2-13. Forward biased diode.

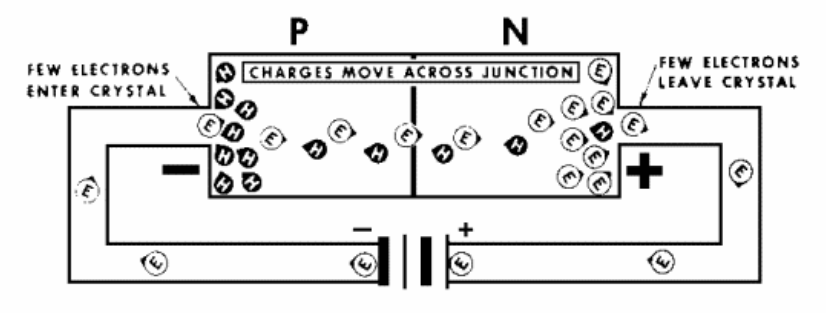


Figure 2-14. Reverse biased diode.

(4) Normally, 1 to 1½ volts are used to forward bias a PN junction diode. If too much forward bias is applied, too much current will flow. The excessive current will cause increasing thermal agitation of the atoms in the semiconductor until the crystal structure of the diode breaks down.

d. PN Junction, Reverse Bias.

(1) If the bias is reversed in a PN junction diode, the holes (majority current carriers) in the P material are attracted by the negative terminal of the battery; they move away from the junction (figure 2-14). Electrons (majority current carriers) in the N material are attracted by the positive terminal of the battery; they also move away from the junction. Since there are very few, if any, holes or electrons left at the junction, very few recombinations occur here.

(2) The reverse biased condition attracts holes away from the PN junction in the P material causing that side of the depletion region to become more negative. Also, the electrons leaving the junction in the N material cause a more positive charge of the depletion region in the N material (figure 2-15). Since the depletion region increases, the potential barrier also increases until its voltage equals the externally applied voltage. Little or no current flows because the two voltages oppose each other.

(3) It is possible to apply a reverse bias voltage larger than the potential barrier; however, the crystal structure of the diode will break down. If it is not damaged, the crystal structure will return to normal when the excess reverse bias is removed. In fact some diodes are specially made to operate in this breakdown region.

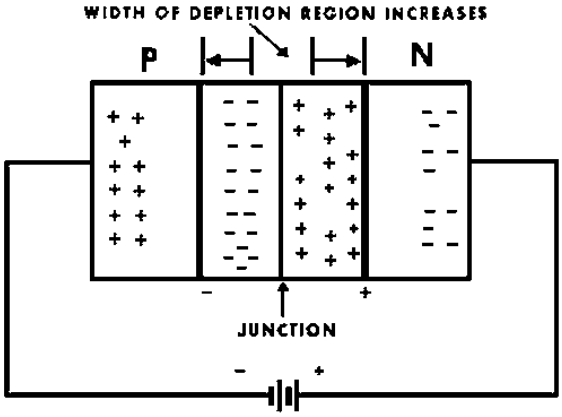


Figure 2-15. Reverse bias effect on depletion region.

e. Characteristic Diode Curve. Figure 2-16 is a curve of a PN semiconductor diode showing current versus applied voltage. Note that current in the forward bias condition is high (measured in milliamperes). However, current with reverse bias, although low (measured in microamperes) is not zero. If the reverse bias is high enough, the junction barrier breaks down and reverse current increases to a high value referred to as the avalanche current. Notice that the value of avalanche current can vary over a wide range as shown between points 1 and 2 without any change in voltage. This is known as the "Zener effect" and is used for voltage regulation.

3. TRANSISTORS.

a. General

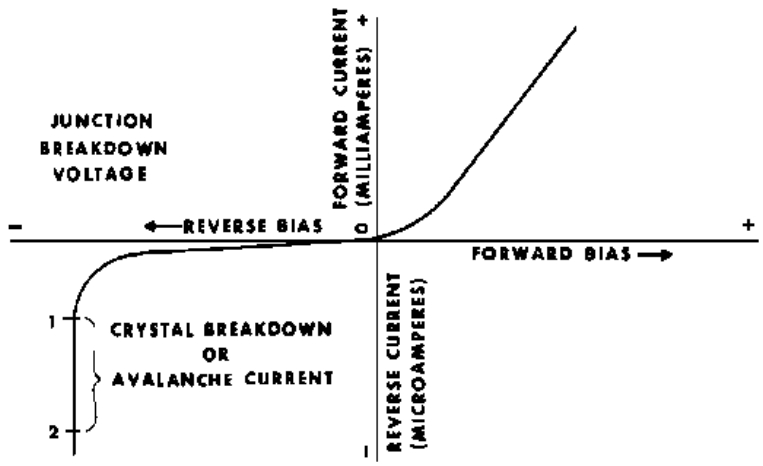


Figure 2-16. Current flow in a PN semiconductor diode.

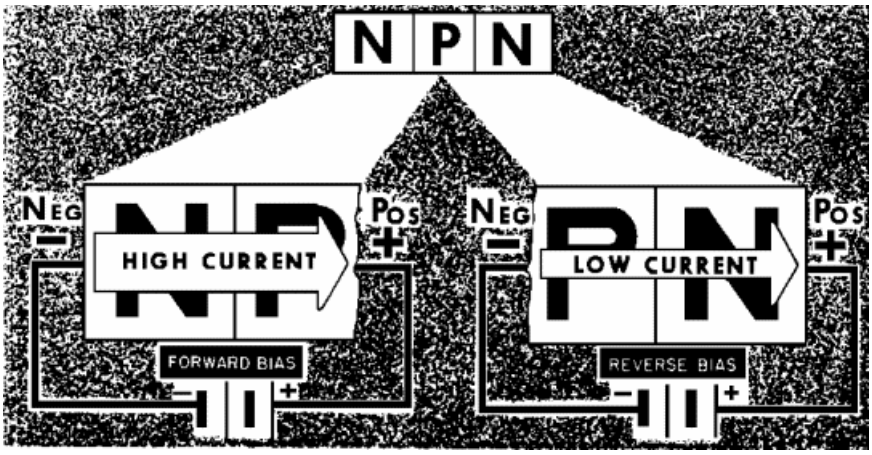


Figure 2-17. Two diode sections of a transistor.

(1) Basically a transistor is a combination of two PN junction diodes (figure 2-17). One PN junction is forward biased and the other is reverse biased.

(2) By joining two PN junction diodes at the P material surfaces a NPN transistor is produced (A, figure 2-18). When joined at the N material a PNP transistor results (B, figure 2-18). Once formed, the different sections of the transistor are identified by the terms: emitter, base, and collector.

b. Emitter, Base, and Collector.

(1) Emitter. The function of the emitter section of a transistor is to emit either electrons (majority current carriers) in an NPN transistor or holes Figure 2-18. Bias methods for NPN and PNP transistors. in a PNP transistor. When electrons or holes leave the emitter, they are forced through the base section towards the collector.

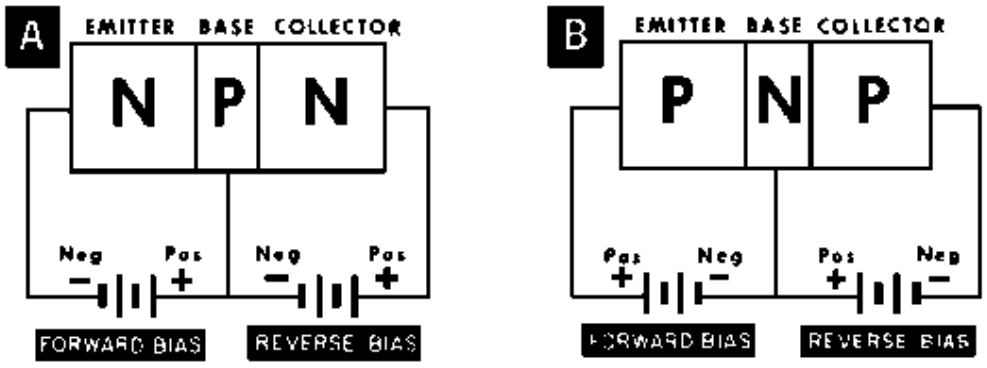


Figure 2-18. Bias Methods for NPN and PNP transistors.

(2) Base. An important physical characteristic of the base is that it is extremely thin compared to the emitter and collector. It has a maximum thickness of 1/1000 inch (figure 2-19). The base has two junctions: an emitter-to base junction, and a base-to-collector junction.

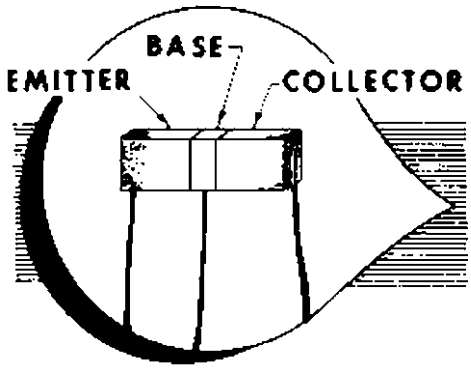


Figure 2-19. Transistor construction.

(3) Collector. Depending on the type of transistor, the function of the collector is to collect either the electrons or the holes from the emitter section.

c. NPN Transistor.

(1) As shown in figure 2-20, the emitter-to-base junction of an NPN transistor must be forward biased. Electrons are the majority current carriers and current flows from the emitter to the base. Electrons that enter the base area meet two attracting forces: one force is the positive terminal of the emitter-to-base battery; and the other is the positive terminal of the base-to-collector battery.

(2) The emitter-to-base battery is called the bias battery and has a very low voltage, for example, 0.1 volt. The base-to-collector battery is called the collector battery and provides a higher value of voltage than the bias battery, for example, 6 volts.

(3) Electrons enter the base traveling at a high speed. Approximately 92% to 98% of them are attracted by the higher value collector battery voltage and travel through the base to the collector. Because the base crystal is extremely thin, electrons leaving the emitter find it easy to pass through it towards the collector. Some of the electrons, however, do not penetrate the base and are attracted to the positive terminal of the bias battery. These few electrons provide a very small base current.

(4) The electrons that pass through the collector and enter the collector battery produce a collector current. Every electron that leaves the collector must be replaced by an electron from the emitter, and every electron that leaves the emitter must be replaced by an electron from the bias battery. This in effect produces a continuous electron flow.

(5) At this point the question may arise of why two batteries and two PN junctions are necessary, when it appears that one battery and one PN junction also produces a continuous current. The most important thing to remember about NPN and PNP transistors is that the bias battery controls the amount of collector current. If the bias battery voltage is increased by a small amount, more electrons leave the emitter and produce a larger collector current. Decreasing the bias voltage decreases the collector current. In a later lesson, how to replace the bias battery with a voltage divider network or with a signal voltage, will be shown. The signal voltage controls the action at the forward biased emitter-to-base junction and produces an amplified signal in the collector circuit.

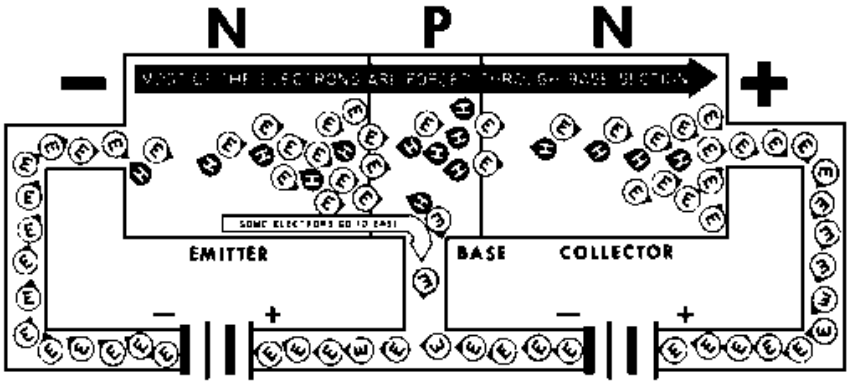


Figure 2-20. Movement of charges in the NPN transistor.

d. PNP Transistor.

(1) In the PNP transistor, the emitter and collector are P-type material and the base is N-type material. During operation, the emitter-to-base junction is forward biased (figure 2-21) and the base-to-collector junction is reverse bias (similar to the NPN transistor). The emitter is connected to the positive side of the bias battery, and the collector is connected to the negative side of the collector battery.

(2) The majority carriers in the PNP transistor are holes. Electrons flow from the external circuit into the collector and out of the emitter (disregarding the small base current).

(3) Forward bias on the emitter-to-base junction causes holes to accelerate towards the base. Most of the holes penetrate the thin base crystal and enter the collector. Holes that arrive in the collector are filled by electrons coming from the negative collector battery terminal. These electrons move through the thin base crystal towards the emitter. In addition a few electrons enter the base from the bias battery and combine with those holes that do not penetrate through to the collector.

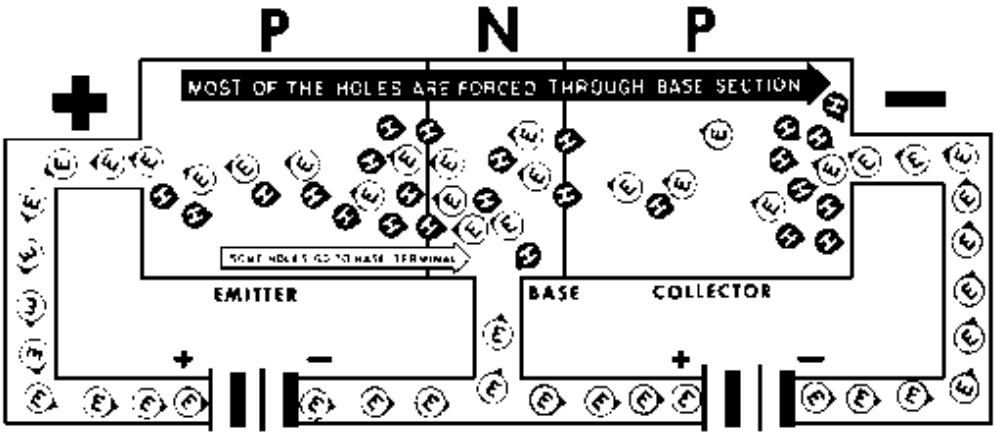


Figure 2-21. Movement of charges in a PNP transistor.

(4) All of the electrons that arrive at the emitter are attracted to the positive terminal of the bias battery. Every electron that flows from the emitter into the bias battery leaves a hole in its place. The holes then move through to the base, to the collector, where they recombine with electrons entering the collector. As with the NPN transistor, a small signal voltage may be applied in place of the bias battery to produce an amplified signal at the collector output.

e. Comparing the Operation of NPN and PNP Transistors.

(1) NPN transistors. The operation of the NPN transistor depends on electrons flowing through the crystal material and through the external circuit outside of the crystal material. Electrons enter the emitter, are forced through the base, and enter the collector. A few electrons do not get through and leave the transistor as a small base current. The majority of the electrons leave the collector as collector current to perform an amplifying function in the external circuit (A, figure 2-22).

(2) PNP transistor. The PNP transistor also depends upon electrons that flow through the semiconductor material and the external circuit. Since the transistor crystal sections are reversed, the electron flow is caused by the movement of holes and is reversed (B, figure 2-22). Electrons enter the collector, flow through the transistor, and leave the emitter to perform an amplifying function in the external circuit.

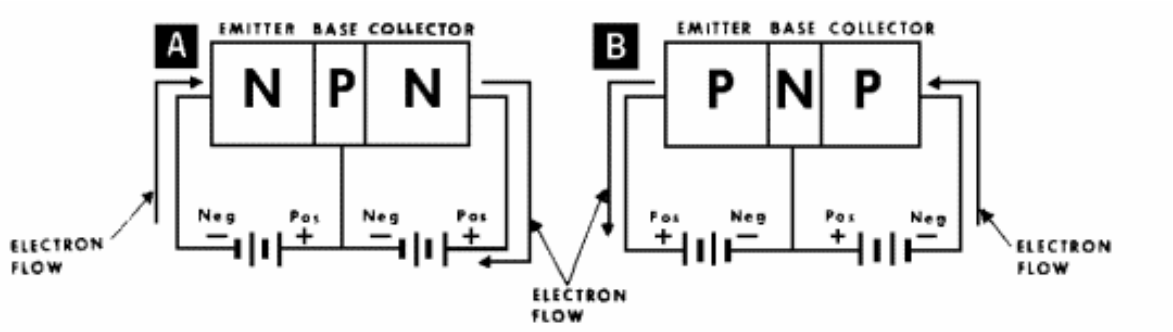


Figure 2-22. NPN-PNP electron flow.

MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS

EXERCISES FOR LESSON 2

1. How many negative particles are found in a silicon atom?

   A. 32
   B. 41
   C. 28
   D. 14

2. Which atom has the least electrons?

   A. Germanium
   B. Phosphorous
   C. Silicon
   D. Aluminum

3. What is another name for the outer ring of electrons in an atom?

   A. Nucleus
   B. Valence
   C. Proton
   D. Neutron

4. What is another name for an electron-pair bond?

   A. Valence
   B. Acceptor
   C. Covalent
   D. Mobile

5. Which is a donor atom?

   A. Arsenic
   B. Aluminum
   C. Boron
   D. Gallium

6. What is the charge of an atom that loses one of its electrons from its outer ring?

   A. Negative
   B. Neutral
   C. Positive
   D. Either positive or negative

7. What is an atom called that either gains or loses an electron?

   A. Neutron
   B. Ion
   C. Minority carrier
   D. Majority carrier

8. If a valence of an atom contains three electrons it is referred to as

   A. donor.
   B. P-type.
   C. N-type.
   D. PN-type.

9. Conduction across a semiconductor occurs because

   A. electron (positive charges) are repelled by the negative voltage.
   B. holes (positive charges) are attracted by the negative voltage.
   C. holes and electrons move in the same direction.
   D. holes (negative charges) are attracted by the positive charge.

10. If current is reversed across a single piece of N or P type material the amount of current

    A. increases slightly.
    B. decreases slightly.
    C. remains the same.
    D. is doubled.

11. Movement of holes and electrons in a PN junction with no external voltage applied is known as

    A. thermal movement.
    B. diffusion.
    C. conduction.
    D. the static charge.

12. What is the approximate barrier potential, in volts, across a germanium semiconductor junction?

    A. 0.001
    B. 0.01
    C. 0.1
    D. 1.0

13. What relationship describes the normal state of an atom?

A. The number of electrons plus the number of protons equals the number of neutrons
B. The number of electrons plus the number of neutrons equals the number of protons
C. The number of electrons equals the number of neurons
D. The number of electrons equals the number of protons

14. What are the current carriers when potential is applied across a N-type germanium material?

A. Bonds
B. Holes
C. Electrons
D. Protons

15. What occurs if a reverse bias voltage is applied across a PN junction diode?

A. Bias voltage increases
B. Bias voltage decreases
C. Barrier potential decreases
D. Barrier potential increases

16. How is a PN junction diode forward biased?

A. Positive terminal of a battery is connected to the positive side of the barrier potential
B. Negative terminal of the battery is connected to the positive side of the barrier potential
C. Negative terminal of a battery is connected to the P-type side of the junction
D. Positive terminal of a battery is connected to the N-type side of the junction

17. What subatomic particles are free to move back and forth across the junction in the formation of the depletion region?

A. Free electrons and positive ions
B. Negative ions and holes
C. Positive ions and negative ions
D. Free electrons and holes

18. When the reverse bias of a PN junction is high enough to cause avalanche current, what is this also known as when used in voltage regulation?

A. Saturation
B. Cutoff
C. Zener effect
D. Breakdown

19. What is the maximum thickness, in inches, of the base in a transistor?

A. 0.1
B. 0.001
C. 0.01
D. 0.0001

20. Normally, what percentage of electrons are attracted to the collector in an operational NPN transistor?

A. 97
B. 3
C. 50
D. 85

LESSON 3. SEMICONDUCTOR DIODE RECTIFIERS AND TRANSISTOR AMPLIFIER FUNDAMENTALS

MMS Subcourse Number 701.....	**Transistors and Semiconductors**
Lesson Objective.....	**To provide the student with a general knowledge of various types of semiconductor rectifier and regulator circuits and transistor amplifier fundamentals.**
Credit Hours.....	**Three**

TEXT

1. RECTIFIER CIRCUITS.

a. General.

(1) The application of semiconductor diode rectifiers for power supplies in electronic equipment continues to increase. The advantages of semiconductor diode rectifiers are: their small physical size, immediate operation without any warm-up time, low operating temperature, and no requirement for filament voltages. Copper-oxide, copper-sulfide, and selenium rectifiers are used primarily in low voltage applications. However, as electronic devices continue to be improved, semiconductor rectifiers are being designed to operate at higher voltages. The small physical size of semiconductor rectifiers, especially the silicon types, makes it practical to combine these units in series to handle higher input voltages.

(2) The symbol for a semiconductor diode rectifier is shown in A, figure 3-1. The term diode indicates that there are two elements, which we call the cathode and the anode. The arrowhead is the anode and the short line that touches the arrowhead is called the cathode. Electrons flow from the cathode to the anode when the diode is forward biased (B, figure 3-1). Bias is the voltage applied between two elements of the diode (cathode and anode). The anode is positive in respect to the cathode and electron flow is opposite to the direction indicated by the anode. When the diode is reverse biased, the anode is negative in respect to the cathode; electrons do not flow through the diode and the diode is said to be cut off (C, figure 3-1).

(3) Most of the electronic equipment used today requires direct current (dc) voltages. An alternating current (ac) power source supplies the input power and it must be converted or rectified to dc (figure 3-2). The semiconductor diode rectifier changes the ac input to a pulsating dc voltage (figure 3-3). To produce a smooth dc voltage of constant amplitude, it is necessary to filter the pulsating dc. Filtering eliminates the rising and falling of the pulsating dc signal (figure 3-4).

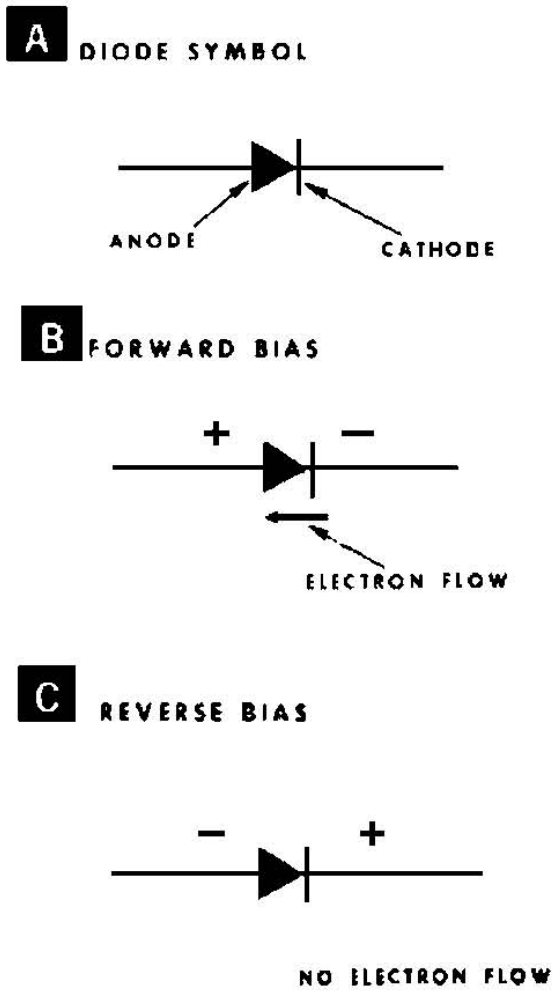


Figure 3-1. Semiconductor diode rectifier.

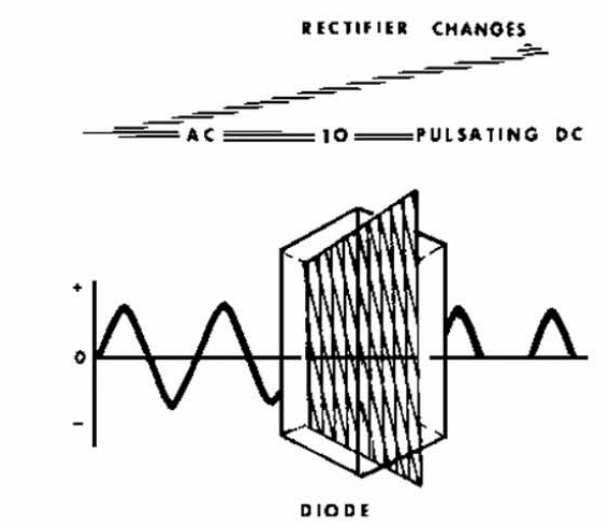


Figure 3-2. Converting ac to pulsating dc.

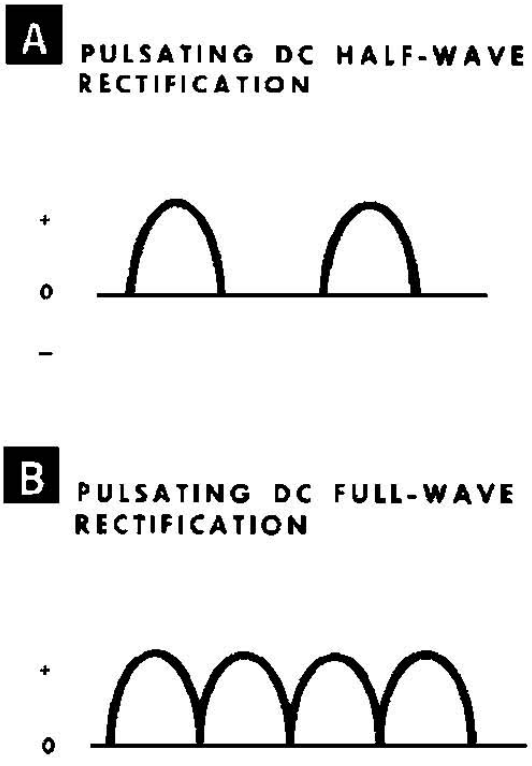


Figure 3-3. Types of pulsating dc.

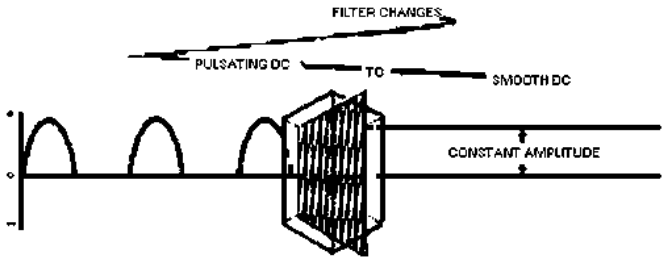


Figure 3-4. Filtering pulsating dc.

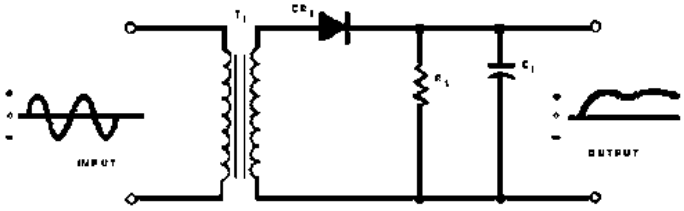


Figure 3-5. Half-wave rectifier circuit.

b. Half-Wave Rectifier. A typical half-wave rectifier circuit (figure 3-5) has a transformer (T1), a diode (CR1), a load resistor (RL), and a filter capacitor (C1).

(1) An ac source voltage is applied to the primary winding of transformer T1. During the positive half cycle, point W is positive in respect to point X (A, figure 3-6).

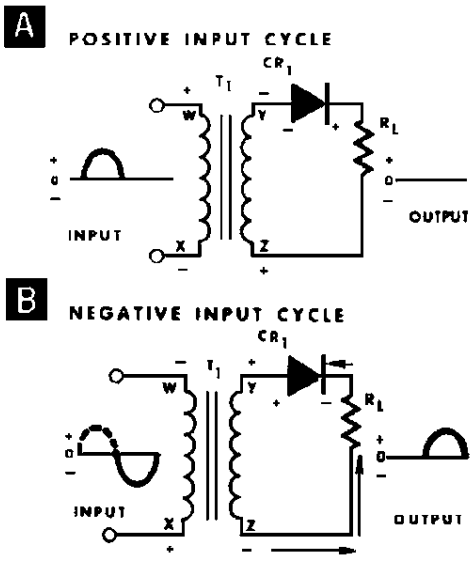


Figure 3-6. Rectifying the ac voltage (half-wave).

(2) A voltage of the opposite polarity is induced in the secondary winding of transformer T1, and point Y is negative in respect to point 2. A negative potential is therefore applied to the anode and a positive potential is applied to the cathode of diode CR1. The diode is reverse biased and does not conduct. No current flows through resistor RL, and there is no voltage developed across resistor RL.

(3) As the ac source voltage across the primary winding is developed during the negative half cycle, point W is negative with respect to point X (B, figure 3-6). A voltage of the opposite polarity is induced on the secondary winding of transformer T1, and point Y is positive with respect to point Z. Diode CR1 is now forward biased. Current flows through the circuit and develops a voltage across resistor RL. The voltage across the resistor follows the ac source voltage and is pulsating dc. Filter capacitor C1 charges to the voltage level developed across RL through diode CR1 (A, figure 3-7), with polarity as shown.

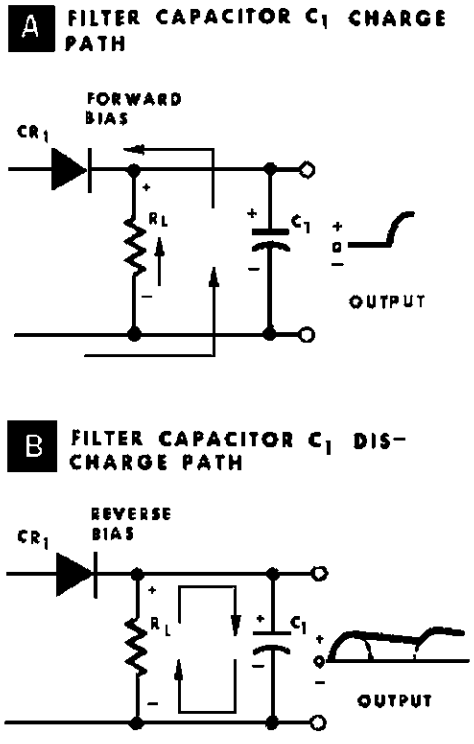


Figure 3-7. Filter action.

(4) While the ac source voltage is in its positive half cycle, diode CR1 is reversed biased (similar to the open contacts of a switch). Filter capacitor C1 discharges through load resistor RL, maintaining a positive voltage at the output terminal (B, figure 3-7). When the input ac source voltage changes to its negative half cycle, filter capacitor C1 charges back to the voltage level across the load resistor. Since this is a continuing action as long as the input voltage is applied, the filter capacitor continues to charge and discharge. For all practical purposes, the filter network (RL and C1) changes the pulsating dc from the diode rectifier to a smooth dc voltage output (figure 3-8).

Figure 3-8. The filter changes the pulsating dc to a smooth dc.

c. Full Wave Rectifier. A typical full wave rectifier circuit has a center-tapped transformer T1, two diodes (CR1 and CR2), a load resistor RL and a filter capacitor (C1) (figure 3-9). The center-tapped transformer supplies operating voltages for the two diodes. Because of the action of the center-tapped transformer, on the positive half cycle of the ac input, one diode is forward biased and conducts. The other diode is reverse biased and cut off. On the negative half cycle of the ac input, the opposite occurs and the diodes switch conduction/cutoff states. Following is a description of the full wave rectifier.

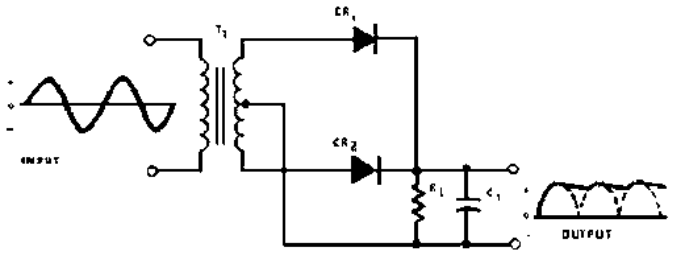


Figure 3-9. Full-wave rectifier circuit.

(1) An ac source voltage is applied to the primary winding of transformer T1.

(a) During the positive half cycle, point V is positive in respect to point W (A, figure 3-10). A voltage of the opposite polarity is induced on the secondary winding of the transformer, and point X is the most negative point, while point Z is the most positive point. Point X is more negative than point Y, and point Y is more negative than point Z. Diode CR1 is reverse biased because the negative voltage at point X is on its anode; diode CR2 is forward biased because the positive voltage at point Z is on its anode.

(b) Current through the circuit develops a voltage across load resistor RL. The current path is from the center top of the secondary of transformer T1 (point Y) through resistor RL, through diode CR2, and back to the secondary. Filter capacitor C1 (figure 3-9) charges to the voltage level of the load
resistor through diode CR2.

(2) As the ac source voltage changes to its negative half cycle, point Y is negative in respect to point W (B, figure 3-10).

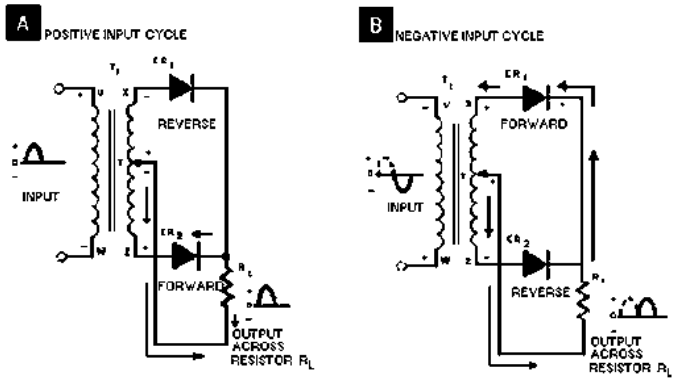


Figure 3-10. Rectifying the ac voltage (full-wave).

(a) A voltage of the opposite polarity is induced on the secondary winding and point X is the most positive point, while point Z is the most negative. Point X is now more positive than point Y, and point Y is more positive than point Z. Diode CR1 is now forward biased because the positive voltage at point X is on its anode and diode CR2 is reverse biased by the negative voltage at point Z.

(b) Current through the circuit continues to develop a voltage drop across load resistor RL. The current path this time is from the center tap of the secondary of the transformer (point Y) through resistor RL, through diode CR1 back to the secondary. Thus, the polarity of the voltage across RL is the same during the entire ac input cycle.

(c) The pulsating voltage developed across RL attempts to follow the input ac voltage (in the positive direction). However, due to the charging and discharging of the filter capacitor C1, the valleys between the pulses will be filled in (figure 3-11). After filtering, the dc output of a full-wave rectifier is smoother than that of a half-wave rectifier.

Figure 3-11. The filter changes the pulsating dc to a smooth dc.

d. Bridge Rectifier. A typical solid-state bridge rectifier circuit (figure 3-12) has a transformer (T1), four diodes (CR1 through CR4), a load resistor (RL), and a filter capacitor (C1). The bridge rectifier circuit is similar in operation to the full-wave rectifier; however, it does not require a center-tapped secondary winding on the input transformer as does the full-wave rectifier. Its output voltage is higher than the full-wave rectifier because the full secondary winding voltage is applied to the semiconductor diodes.

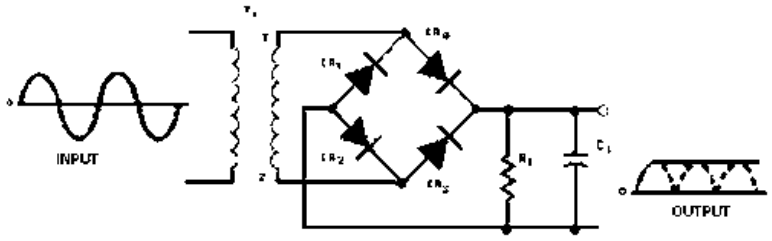


Figure 3-12. Bridge rectifier circuit.

(1) During the positive half cycle of the input ac voltage, a negative voltage is induced at point Y, and a positive voltage is induced at point Z (A, figure 3-13). Current flow is from the negative side of the secondary (point Y), through diode CR1, through load resistor RL, through diode CR3 back to the positive side of the secondary (point Z). It appears that the current leaving the top of the load resistor has two paths back to the secondary; one through diode CR3, and the other through diode CR4. You must remember that the current started from the most negative point of the secondary and has to return to the most positive point. If the path were through diode CR4, the current would be returning to the most negative point of the secondary. If you look at the voltages applied to diode CR4, you will see that diode CR4 is reverse biased (negative on its anode and positive on its cathode) and is an open circuit to the current from the load resistor. Therefore, diode CR3 is the return path for current. The voltage across the load resistor follows the ac source voltage during its positive half cycle.

(2) During the negative half cycle of the ac input, point Y is positive in respect to point Z (B, figure 3-13). Current flows from the negative side of the secondary (point Z), through diode CR2, through load resistor RL, and through diode CR4 back to the positive side of the secondary (point Y). The return current path at the junction of diodes CR3 and CR4 is similar to that during the positive half-cycle, except that now diode CR3 is reverse biased; it does not offer a return path back to the secondary. The voltage developed across the load resistor will follow the source voltage but in the positive direction. In effect, the negative half cycle of the input is changed to a positive half cycle at the output. Filter action is the same as in the full-wave rectifier.

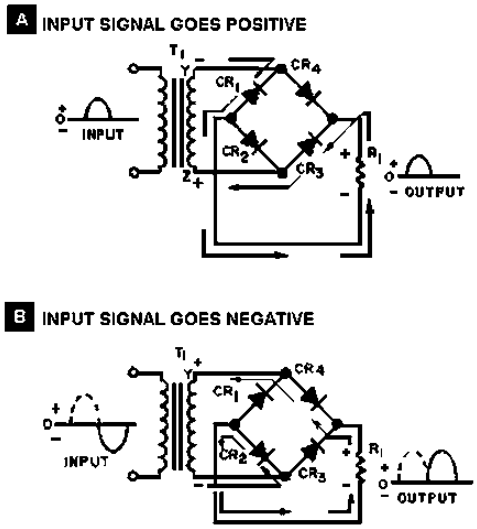


Figure 3-13. Rectifying the ac signal (bridge rectifier).

e. Voltage Doubler Circuits. Voltage doubler circuits produce a higher dc output voltage than a conventional rectifier circuit. The voltage doubler is normally used when the load current is small and voltage regulation is not critical; it can be used as a power supply in small transistor radios, and in some transmitters as a bias supply. As the term voltage doubler implies, the output voltage is approximately twice the input voltage. Two types of voltage doubler are used: the halfwave and the fullwave.

(1) Operation of a half-wave voltage doubler (A, figure 3-14). During the positive half cycle of the input ac voltage, point Y is at a negative potential and point Z is at a positive potential (B. figure 3-14). Current flows (as indicated by the arrows) from the negative terminal (point Y) to capacitor C1, through diode CR1, and back to the positive terminal of the secondary winding point Z. Capacitor C1 charges to EC1 (B, figure 3-15), a charge almost equal the peak value of the input source voltage. During the negative half of the input cycle, the polarity across the secondary winding changes (C, figure 3-14). The voltage (EC1) across C1 is in series with the voltage across the secondary winding and adds to the peak value of the input voltage. Current now flows from point Z through the load resistor, and CR2, to C1 and back to point Y of the secondary. During this half cycle C2 charges to EC2 which is equal to the peak value of the input voltage plus the charge across C1. The charge EC2 is approximately double the value of the input source voltage. C2 is charged only on alternate half cycles of the input voltage; it discharges through the load resistor and produces output waveform (C, figure 3-15).

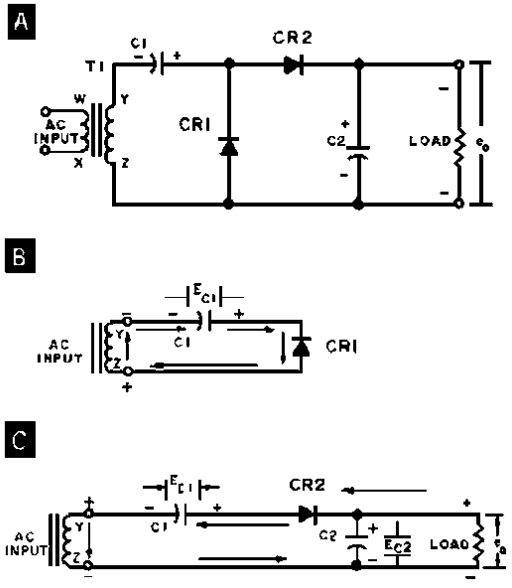


Figure 3-14. Half-wave voltage doubler.

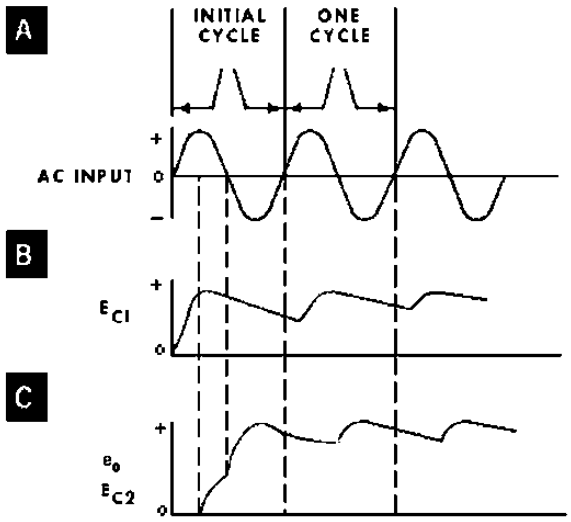


Figure 3-15. Half-wave voltage doubler waveforms.

(2) Full-wave voltage doubler. The voltage regulation of the full-wave voltage doubler is better than that of the half-wave voltage doubler because of the full-wave rectification. This circuit is generally used where the load current is small and relatively constant. In the full-wave voltage doubler, capacitors C1 and C2 are charged on alternate half cycles of the applied voltage; then their charges are added together to provide the output voltage to the load (A, figure 3-16).

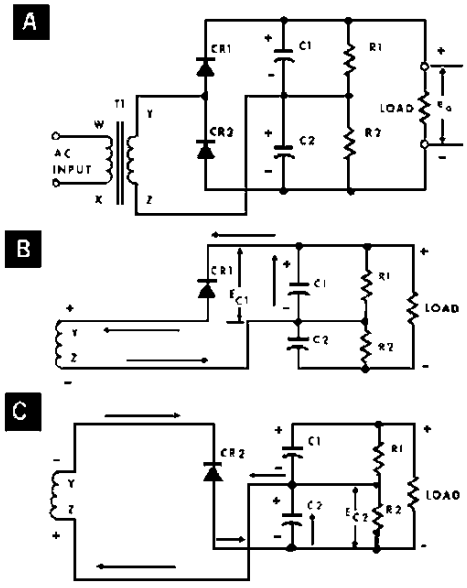


Figure 3-16. Full-wave voltage doubler.

(a) Assume that the ac-input voltage makes point Y positive in respect to point Z of the secondary winding of transformer T1 (B, figure 3-16). Current flows from the negative point Z to capacitor C1, to diode CR1, and back to the positive point of the secondary. This charges capacitor C1 to approximately the peak value of the applied ac voltage. B, figure 3-17, shows how capacitor C1 charges.

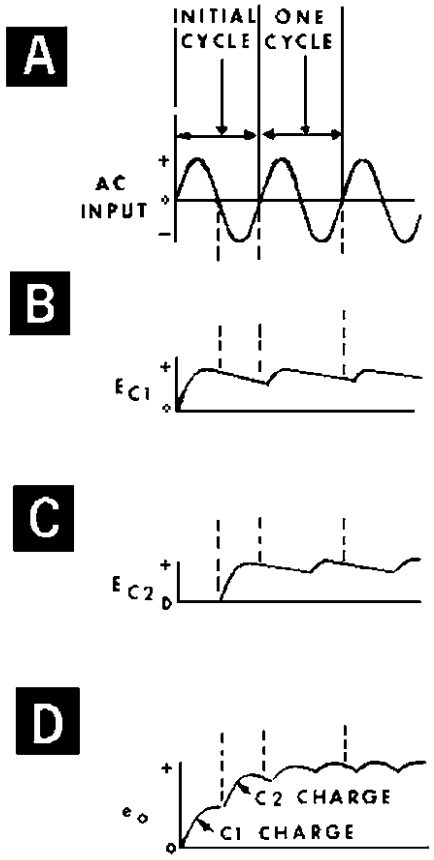


Figure 3-17. Full-wave voltage doubler waveforms.

(b) During the next half cycle, point Y is negative in respect to point Z (C, figure 3-16). Current now flows from point Y, to capacitor C2, and back to the positive side of the secondary winding, point 2. During this half cycle, capacitor C2 also changes (EC2) to approximately the peak value of the input ac voltage (C, figure 3-17).

(c) Capacitors C1 and C2 are connected in series and their combined voltage appears across resistors R1 and R2. Therefore, the voltage across both resistors equals the charge on both capacitors. Since the load is connected in parallel with the capacitor and resistor combination, the output voltage to the load is equal to approximately twice the peak voltage of the ac voltage input (D, figure 3-17).

f. Zener Diode. If we reverse bias a semiconductor diode, current does not stop; it continues at a low rate (a few micro-amperes) until the bias is increased to the diode breakdown voltage. If the reverse bias is continually increased beyond the breakdown point, current suddenly increases. This is called the avalanche effect: it will destroy the diode due to overheating except in the special case of the Zener diode.

(1) The Zener diode is a PN junction diode. While it is being manufactured, it is modified so that its breakdown voltage level can be controlled over a range of from 2.5 volts to about 200 volts. Each Zener diode has its own specific breakdown voltage, depending on how it is made, and must be selected for the desired operating voltage. The symbol for the Zener diode is shown in figure 3-18.

Figure 3-18. Zener diode symbol.

(2) A voltage regulating circuit using a Zener diode is shown in figure 3-19. If the Zener diode breakdown voltage is 10 volts and the voltage applied to the circuit is 12 volts, then the diode will conduct. Since the diode is rated at 10 volts and 12 volts are applied, then 2 volts will be developed across resistor R2 which is in series with the diode. The voltage developed across the load will be 10 volts (load resistor R1 is in parallel with the diode). If the applied voltage increases to 15 volts, the diode will continue to operate at its breakdown voltage of 10 volts. The voltage increase, now 5 volts, will be developed across resistor R2. The voltage across the load will be maintained at 10 volts. Thus, any voltage change above 10 volts appears across series resistor R2 and the load voltage remains constant.

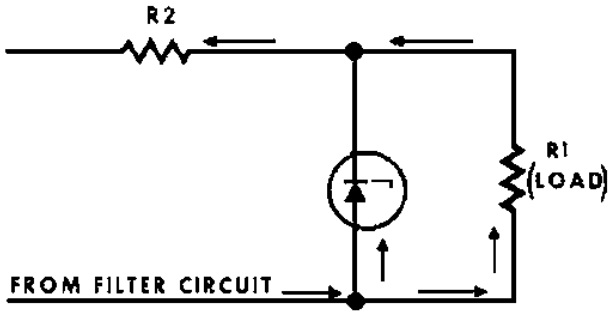


Figure 3-19. Voltage regulating circuit with a Zener diode.

2. SEMICONDUCTOR VOLTAGE REGULATOR.

a. General.

(1) It is said that the filtered output of a rectifier supplies a constant dc voltage. However, the voltage output of a power supply may not always be constant; it can vary with fluctuations in the load that it is supplying, in the power supply itself, and in input ac line voltage. To compensate for possible fluctuations, voltage regulator circuits have been developed to keep the output of a power supply at a constant level.

(2) Generally, a voltage regulator is a variable resistance, in fact or in effect, and is connected in series at the output of the rectifier-filter circuit. The regulator (variable resistance) and the load (resistance) form a voltage divider. The voltage across the load can be held constant by controlling the variable resistance of the regulator.

b. Basic Voltage Regulator. As shown in figure 3-20, variable resistor R and the load resistance form a voltage divider across the output terminals of the power supply. Output current from the power supply passes through both the load and the variable resistor and develops a voltage across both. If the output voltage of the power supply increases, the voltage across the load will increase in proportion to its resistance. To counteract this increase in voltage across the load, the resistance of R can be increased to drop more of the output voltage across it. Thus, the voltage across the load can be held constant by varying the resistance of R each time the output voltage of the power supply changes. To regulate the output of the circuit in figure 3-20, it would be necessary to monitor voltmeter V constantly and manually increase or decrease the resistance of R each time the output tried to change.

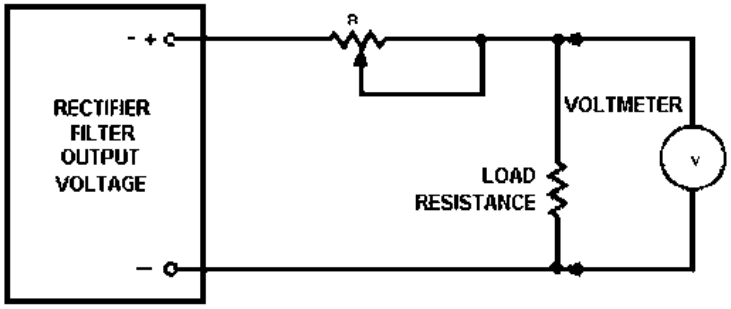


Figure 3-20. Basic regulator circuit.

This same type of action takes place in a voltage regulator circuit, except that once the output voltage is set at a desired value, the action of the regulator is automatic.

c. Transistorized Voltage Regulator. Transistor Q1 in figure 3-21 is called a series regulator because it is connected in series with one side of the filtered output of the power supply. Transistor Q2 controls the amount of current through transistor Q1. By controlling the current through Q1, the resistance is also controlled. The more current that flows through Q1, the lower will be its resistance; the less current through Q1, the higher its resistance. The Zener diode and resistor R1 are used to provide a constant reference voltage for the base of transistor Q2.

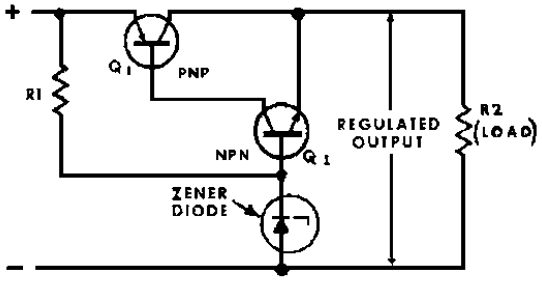


Figure 3-21. Transistor voltage regulator circuit.

(1) To see how this automatic voltage regulator circuit works, assume that the output voltage from the power supply increases 2 volts. The 2-volt increase is applied to the emitter of Q2, but the base voltage on Q2 remains steady because of the Zener diode. The increased positive voltage on the emitter of Q2 causes Q2 to conduct less and its collector voltage rises in a positive direction. The higher positive collector voltage of Q2 causes the base of Q1 to become more positive, in effect increasing reverse bias on the base of Q1. With a higher reverse bias, the internal resistance of Q1 rises just enough to develop an additional 2-volt drop across it to absorb the 2-volt increase in the output of the power supply.

(2) If the output voltage from the power supply drops 2 volts, then the opposite actions take place. The resistance of Q1 decreases so that more current is supplied to the load and keeps the load voltage constant. In this case, the lower output voltage of the power supply is applied to the emitter of Q2. With its emitter voltage less positive (more negative), Q2 conducts more and its collector voltage becomes less positive (more negative). The collector voltage from Q2 decreases the reverse bias of Q1; Q1 conducts more, its internal resistance decreases, and allows more current to be supplied to the load.

(3) Although the regulator circuit reactions in a. and b. above happen in the described sequence, they are instantaneous. The load does not feel the fluctuations in the power supply and the voltage across the load remains constant. At the same time, variations in the load itself produce the same reactions in the regulator as if the output of the power supply were fluctuating. A decrease in the load (lower resistance, less voltage drop) causes the voltage regulator to react as if the output of the power supply tried to increase. An increase in the load produces an opposite reaction by the regulator.

d. A Modified Voltage Regulator Circuit. Figure 3-22 shows a slightly modified version of the transistorized voltage regulator circuit. The differences between this circuit and the one covered in paragraph 2c are: a Zener diode provides a constant voltage on the emitter of transistor Q2; and, a portion of variations of the load voltage is used to change the bias of transistor
Q2.

(1) Assume that the voltage across load resistors R2 and R3 tries to increase because of an increase in the output of the power supply. Immediately, the base of Q2 becomes more negative and causes Q2 to conduct more. The collector voltage of Q2 becomes more positive (less negative) and increases the reverse bias at the base of Q1. Q1 conducts less; its internal resistance increases, causing an increased voltage drop across Q1. This increased voltage drop decreases the output of the power supply. Thus the load voltage remains constant.

(2) If the voltage across the load tries to decrease, Q2 will conduct less. The collector of Q2 will become more negative, increasing the forward bias of Q1. Transistor Q1 will conduct more and its internal resistance will decrease. Since less voltage will be developed across Q1, the voltage across the load will remain constant.

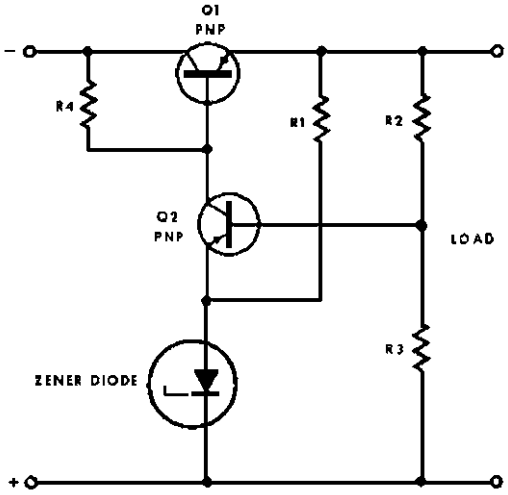


Figure 3-22. Modified voltage regulated circuit.

3. TRANSISTOR SCHEMATIC SYMBOLS. The symbols used for PNP and NPN transistors on schematic diagrams are in figure 3-23. The letter Q followed by a number designates a particular transistor on a schematic. As an example, Q4 is transistor number 4. The symbol also indicates if the transistor is an NPN or a PNP. The emitter symbol always has an arrowhead that either points into or out of the transistor.

a. Pointing iN P. If the arrowhead points into the transistor, this is the symbol for a PNP transistor (A, figure 3-23). Within a PNP transistor, holes (majority current carriers) must flow from the emitter to the collector, so the collector must be negative with respect to the emitter. In the external circuit, electrons flow opposite to the direction of the emitter arrow (B, figure 3-23).

b. Not Pointing iN. If the emitter arrow does not point into the transistor, this is the symbol of an NPN transistor (C, figure 3-23). Within a NPN transistor, electrons (majority current carriers) must flow from emitter to collector, so the collector must be positive with respect to the emitter. In the external circuit, electrons flow opposite to the direction of the emitter arrow (D, figure 3-23).

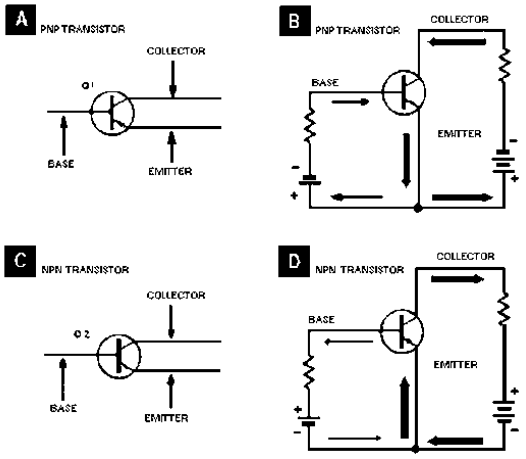


Figure 3-23. Transistor schematic symbols.

4. AMPLIFIER CONFIGURATIONS. Transistor amplifiers may be connected in any one of three basic configurations. They are the common emitter (CE), the common base (CB), and the common collector (CC). These three arrangements correspond to three similar electron tube circuits. The common emitter is similar to a conventional amplifier. The common base is similar to a grounded grid amplifier. The common collector is similar to a cathode follower. The term common (or grounded) indicates that the particular element of the transistor is associated with both the input and output signals.

5. COMMON EMITTER AMPLIFIER. In the common emitter amplifier circuit, the input signal is injected into the base and the output signal is taken from the collector. Most common emitter amplifiers give voltage gains (amplified output signals) of 300 to 1000. There is a polarity reversal in this configuration; the output signal is opposite to the input signal in polarity.

a. NPN Transistor in a Common Emitter Circuit. A basic NPN common emitter amplifier is shown in A, figure 3-24. Electron flow is in the direction of the small arrows. It works as follows:

(1) No signal input. Assume that there is no input signal; the circuit is operating in its steady or quiescent (no signal) state. The base is at some positive potential compared to the emitter, the amount depending upon the values of the bias battery and base resistor (RB). Current through the transistor develops a voltage across the load resistor (RL). Since the positive terminal of the collector battery is in series with RL and the collector, the voltage developed across RL lowers the positive potential at the collector. Note that the voltage across the load resistor opposes the collector battery. For example, if the collector battery voltage is 24 volts and RL develops a voltage drop of 12 volts, then the voltage at the collector is + 12 volts. This is the steady state (no signal) value of collector voltage. If the transistor is allowed to conduct more, then RL will develop a larger voltage drop and the positive potential at the collector will be lower. If the transistor conducts less, then RL develops less voltage and the collector will have a higher positive potential.

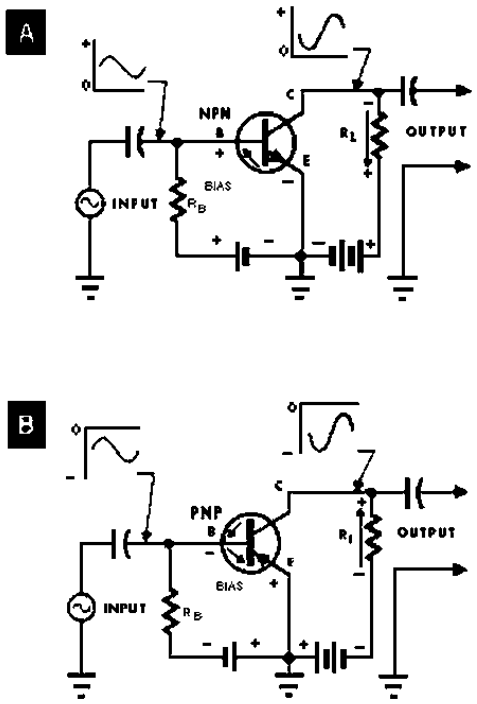


Figure 3-24. Common emitter (CE) amplifier.

(2) Positive half input cycle. Consider an instant of time when an applied input voltage is positive and aids the forward bias of the emitter-to-base junction. The increased forward bias increases the current through the emitter. The collector and base currents are also increased. The increased current through the load resistor causes the top of the resistor to become more negative. In effect, this lowers the positive potential of the collector. For the entire half-cycle that the input signal goes positive and aids the forward bias, the output signal goes in the negative direction (collector voltage becomes less positive).

(3) Negative half-input cycle. When the input signal voltage is negative and opposes the forward bias of the base-to-emitter junction, the decreased forward bias decreases the emitter current. The collector and base currents also decrease by corresponding amounts. The decreased collector current through the load resistor causes the top of the resistor to become less negative (less opposition to the collector battery). In effect, the collector voltage becomes more positive. For the entire half cycle that the input signal goes negative and opposes the forward bias, the output signal goes positive.

(4) Phase inversion. The output signal of the NPN common emitter amplifier is 180 degrees out of phase with the input signal.

b. PNP Transistor in a Common Emitter Circuit. B, figure 3-24, shows a basic PNP common emitter amplifier. Electron current is indicated by the small arrows. The PNP common emitter amplifier circuit operates similar to the NPN circuit except that the two batteries are reversed.

(1) No signal input. With no input signal, the collector voltage is at some steady negative value due to the negative potential from the collector battery.

(2) Positive half input cycle. During the time that the input signal is positive, it opposes the bias battery. The forward bias is reduced and current through the transistor decreases. The voltage drop across load resistor RL decreases and the collector goes in a negative direction.

(3) Negative half input cycle. When the input signal swings negative, it aids or increases the emitter-to-base forward bias. The transistor conducts more and the voltage drop across load resistor RL increases. The collector goes in a positive direction.

(4) Phase inversion. Similar to the output of the NPN circuit, the output signal of the PNP common emitter amplifier is 180 degrees out of phase with the input.

6. COMMON BASE AMPLIFIER. In the common base amplifier circuit, the input signal is injected into the emitter and the output signal is taken from the collector. The circuit has a low input resistance (30 to 160 ohms) and a high output resistance (250 k to 550 k). The common base amplifier is an impedance matching circuit used to match a low impedance circuit to a high impedance circuit. It has a voltage gain of about 1000 and a current gain of less than one. There is no phase change between input and output signals. Both the input and output signals are in phase.

a. NPN Transistor in a Common Base Amplifier. A, figure 3-25, shows a basic NPN common base amplifier. Electron flow is indicated by the direction of the small arrows.

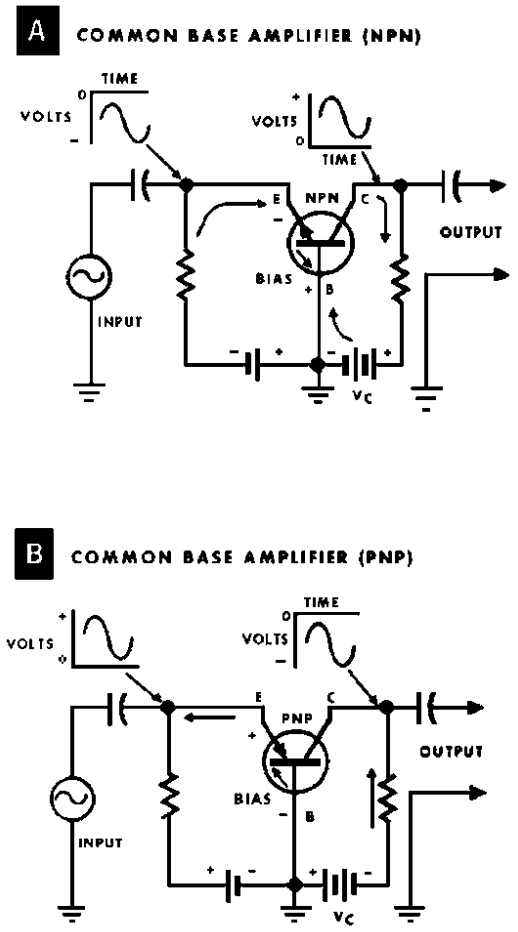


Figure 3-25. Common base (CB) amplifier.

(1) No signal input. In the quiescent state (no signal input), there is some positive voltage at the collector. The emitter is at some negative voltage determined by the value of the bias battery and emitter-to-base resistor.

(2) Positive input cycle. During the positive half of an input cycle, the input signal opposes the forward bias of the emitter-to-base junction. The forward bias is reduced and causes reduced current through the circuit. The reduced current through the load resistor causes a smaller voltage drop and the top of the resistor to become less negative (or more positive) compared to the bottom of the resistor. Another way of stating this action is that less current through the circuit raises the collector voltage toward the collector battery positive potential. The result is that as the input signal swings positive, the output signal also swings positive.

(3) Negative half input cycle. During the negative half of the input cycle, the input signal aids the emitter-to-base forward bias. As the forward bias increases, the total current in the circuit increases. The load resistor develops a higher voltage drop, which, in effect, reduces the positive potential at the collector. The result is that as the input signal swings negative, the output signal also swings negative.

b. PNP Transistor in a Common Base Amplifier. B, figure 3-25, shows a basic PNP common base amplifier. Notice that the circuit is the same as the NPN except that the two batteries are reversed. When the input signal swings positive, the forward bias of the emitter-to-base junction increases. More current flows through the circuit and develops a higher voltage across the load resistor. The voltage across the load resistor opposes the collector battery, making the collector less negative (more positive). On the other hand, the negative half of the input cycle decreases the emitter-to-base forward bias and reduces current through the load resistor. Less voltage dropped across the load resistor causes a more negative voltage at the collector. As in the NPN circuit, the input and output signals are in phase with each other.

7. COMMON COLLECTOR AMPLIFIER. In the common collector circuit (figure 3-26), the input signal is injected into the base and the output signal is taken from the emitter. This circuit is also known as an emitter follower and is used for impedance matching and isolation of output stages. It matches a high impedance circuit to a low impedance circuit. The output signal is in phase with and of the same polarity as the input. The circuit has a high input resistance (2 k to 500 k) and a low output resistance (50 to 1500 ohms). Its voltage gain is less than one but its current gain is about 25; its voltage output is never greater in amplitude than the input.

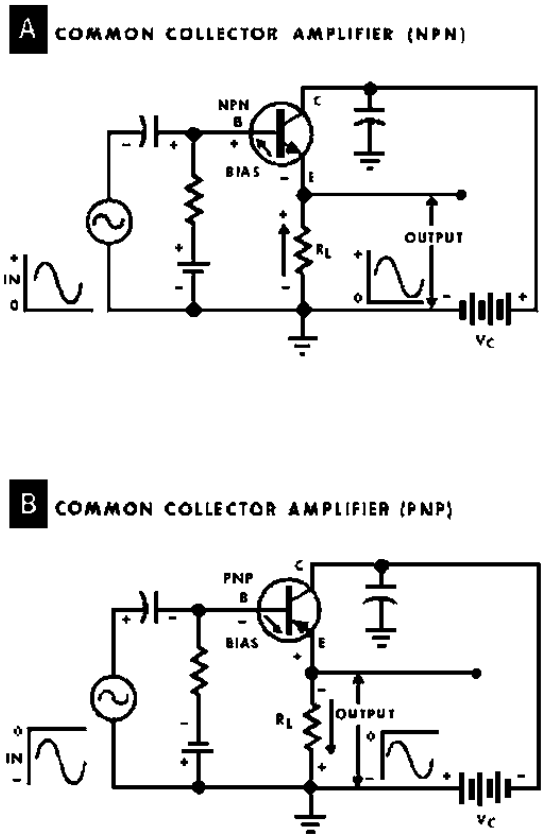


Figure 3-26. Common collector (CC) amplifier.

a. NPN Transistor in a Common Collector Amplifier. A basic NPN common collector amplifier is shown in A, figure 3-26. Electron current is indicated by the direction of the small arrows.

(1) No signal input. During the quiescent state, there is a positive potential with respect to ground at the top of the load resistor. However, with respect to the base, the emitter is at some negative potential determined by the value of the bias battery.

(2) Positive half input cycle. When the positive half of an input cycle is applied, input voltage aids the emitter-to-base forward bias which increases the total emitter current. The increased current through the load resistor causes the voltage at the top of the resistor to become more positive (than it was during quiescence). The output signal is taken across the load resistor which is part of the emitter circuit. Thus as the input swings positive, the voltage across the load resistor swings positive.

(3) Negative half input cycle. When the input cycle swings negative, it opposes the emitter-to-base forward bias which reduces the emitter current. The reduction in emitter current causes the top of the load resistor to become less positive (than it was during quiescence). As a result, the output signal swings negative as the input swings negative.

b. PNP Transistor in a Common Collector Amplifier. A basic PNP common collector amplifier is shown in B, figure 3-26. The operation and the circuit is the same as the NPN common collector amplifier except the reversal of the two batteries. As the input signal increases or decreases the emitter-to-base forward bias, the variations across the emitter circuit follow these changes.

8. SINGLE BATTERY BIAS ARRANGEMENTS. Proper biasing of a transistor amplifier, regardless of the circuit used, consists of forward bias on the emitter-to-base junction and reverse on the collector-to-base junction. In previous circuit examples two batteries were used for biasing voltages. It is possible, however, to get proper biasing with only one battery.

a. Common Base Single Battery Bias. You need a voltage divider network to operate a common base amplifier with a single battery (figure 3-27). The transistor in the figure is a PNP type. Reverse bias is achieved by making the collector negative with respect to the base. Note that the collector connects to the negative battery terminal through resistor R2. To get forward bias in the emitter-to-base circuit, the emitter has to be positive with respect to the base. Resistors R3 and R4 provide the forward bias needed. Current from the battery is through R3 and R4 and causes a voltage drop with the indicated polarities across the two resistors. The voltage drop across R3 makes the base negative with respect to the emitter (or, the emitter is positive compared to the base). For operation of the NPN transistor, simply reverse the battery.

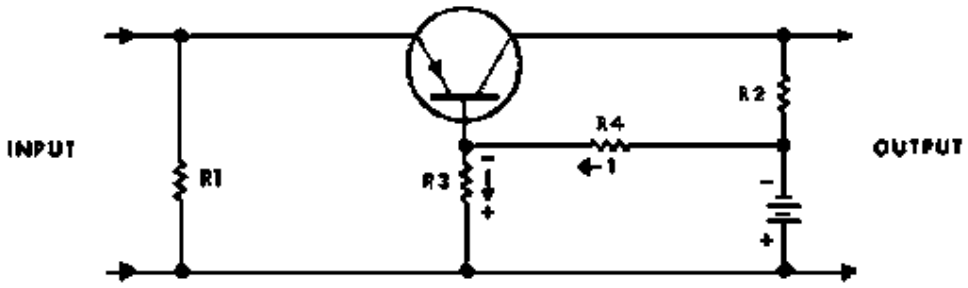


Figure 3-27. Common base amplifier with single battery bias.

b. Common Emitter Single Battery Bias. The common emitter amplifier may also be biased with a single battery (figure 3-28).

(1) To forward bias an NPN transistor, the base has to be positive in respect to the emitter (A, figure 3-28). The base, being physically between the collector and emitter, assumes a value of voltage between their voltages. The base must be less negative than the emitter (positive compared to the emitter). The value of the voltage between the emitter and base must be very small, compared to that between the collector and base. Remember that internally, the two PN junctions act as a voltage divider. The collector-to-base junction represents a high resistance and develops the larger voltage drop. The emitter-to-base junction represents a low resistance and develops the lower voltage drop.

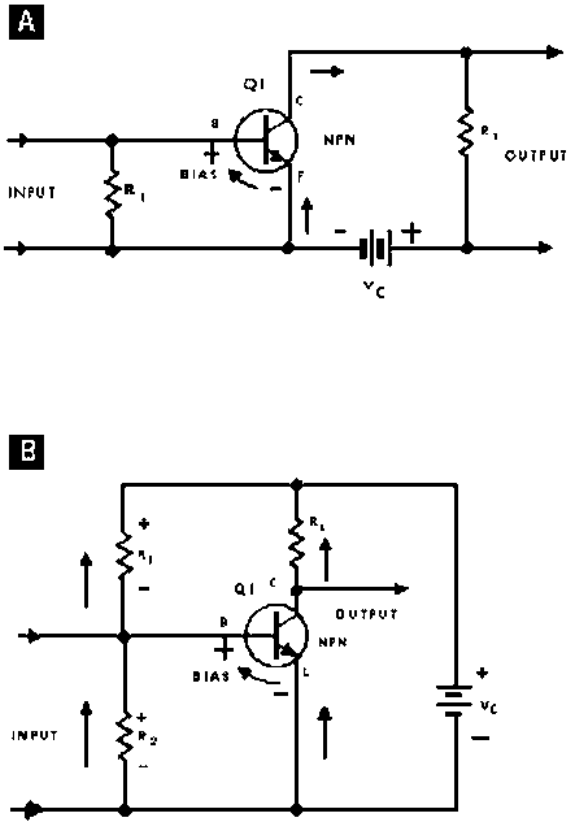


Figure 3-28. Common emitter amplifier with single battery bias.

Current from the emitter to the base (low resistance) sets up a negative-to-positive potential, with the base positive compared to the emitter. This potential is approximately 0.1 volt and eliminates the need for an external bias battery.

(2) B, figure 3-28, shows another method of using a single battery to provide bias for a common emitter amplifier. Resistors R1 and R2 form a voltage divider and R2 is smaller in value than R1. Current through the voltage divider produces voltage polarities across the resistors as shown. The low voltage developed across R2 forward biases the emitter-to-base junction and eliminates the need for an external bias battery. The higher voltage developed across R1 reverse biases the second PN junction (base-to-collector).

(3) PNP transistors can also be biased with a single battery as in (a) and (b) above except that the battery must be reversed.

c. Common Collector Single Battery Bias. The common collector amplifier can also be biased with a single battery (figure 3-29). The base-to-collector reverse bias is established by the battery. The forward bias of the emitter-to-base junction is provided by current through the small resistance of the emitter-to-base junction, with the polarity as shown. The NPN transistor emitter is negative compared to the base (forward bias).

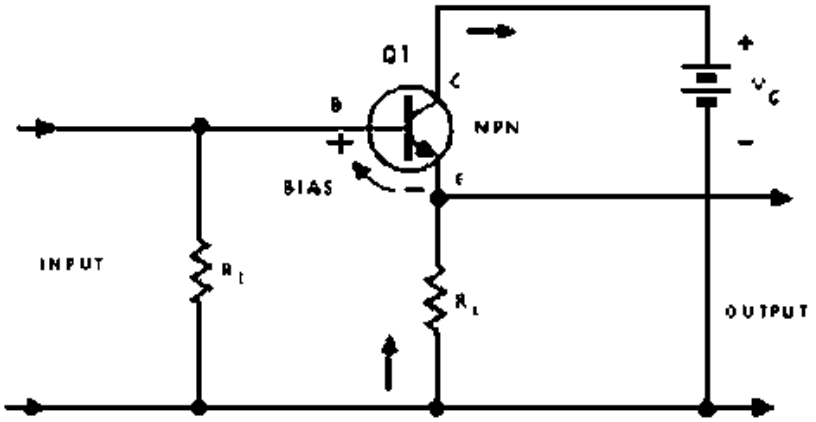


Figure 3-29. Common collector amplifier with single battery bias.

MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS

EXERCISES FOR LESSON 3

1. What is the advantage(s) of a semiconductor diode rectifier?

   A. Low operating temperature
   B. No requirement for filament voltages
   C. Small size
   D. All of the above

2. Which is NEVER used in the construction of a rectifier?

   A. Copper-oxide
   B. Phosphorous
   C. Selenium
   D. Copper-sulfide

3. Electron flow in a semiconductor diode rectifier, when forward biased, is from

   A. anode to collector.
   B. base to cathode.
   C. cathode to anode.
   D. anode to cathode.

4. What would be the output of the half-wave rectifier shown in figure 3-5 if capacitor C1 opens?

   A. No change
   B. Pulsating positive pulse
   C. Pulsating negative pulse
   D. Pulsating positive pulse with reduced filtering

5. When does capacitor C1 in figure 3-5 discharge?

   A. Input ac signal is in the positive half cycle
   B. Only when CR1 conducts
   C. Input ac signal is in the negative half cycle
   D. When a fixed charge is attained on C1 regardless of the ac input

6. If the Zener in figure 3-19 is rated at 10 volts, how much voltage is dropped across resistor R2 if 15 volts is applied to the input?

   A. 2
   B. 5
   C. 15
   D. 10

7. When is the voltage doubler normally used?

   A. Only when critical voltage regulation is necessary
   B. When the load current is small and voltage regulation is not critical
   C. Normally when load current is high
   D. Whenever an increase in load current is needed along with critical voltage regulation

8. The valleys in the output of the rectifier shown in B of figure 3-13 are filled in by the action of an additional component, namely a

   A. ground connection to the center of the transformer secondary.
   B. second capacitor to the output circuit.
   C. capacitor across the load resistor.
   D. diode across the load resistor.

9. Refer to the rectifier circuit shown in figure 3-12. If point Z is positive, which diodes are forward biased?

   A. CR1 and CR2
   B. CR1 and CR3
   C. CR2 and CR3
   D. CR2 and CR4

10. What best describes the function of Q1 in figure 3-21?

   A. Variable resistor
   B. Amplifier
   C. Voltage divider
   D. Output sensor

11. In figure 3-22, what resistor(s) is/are utilized as load resistors?

   A. R1 and R2
   B. R1, R2, and R3
   C. R3 and R2
   D. R3 only

12. The output voltage of the half-wave voltage doubler shown in figure 3-14 results from

   A. charge of capacitor C2 through CR2.
   B. input voltage plus charge on C1.
   C. discharge of C1 through CR1.
   D. breakdown of CR2 during a positive cycle input.

13. In the three basic amplifier configurations of common emitter, common base, and common collector, the term COMMON refers to the transistor lead that

A. is associated directly with both the input and output signals.
B. connects to the input of another transistor in the circuit.
C. is associated only with the input of the same transistor.
D. connects to a similar lead of another transistor.

14. What is the phase relationship between the input and output signals of the common-emitter amplifier?

A. In phase
B. 45 degrees out of phase
C. 90 degrees out of phase
D. 180 degrees out of phase

15. In transistor amplifiers, the input signal is injected in one section and the output is removed from another section. Which two sections are used in the common-base amplifier circuit?

	Input	Output
A.	Base	Emitter
B.	Base	Collector
C.	Emitter	Collector
D.	Emitter	Base

16. The common-emitter amplifier has both a high voltage gain and a high current gain. In comparison, the common-base amplifier has a

A. low voltage and high current gain.
B. high voltage and high current gain.
C. low voltage and low, or no, current gain.
D. high voltage and low, or no, current gain.

17. In a common-base amplifier circuit, a comparison of signals reveals that the output and input signals are

A. in phase.
B. 45 degrees out of phase.
C. 90 degrees out of phase.
D. 180 degrees out of phase.

18. Describe the magnitude of input resistance relative to output resistance in a common-collector amplifier.

A. It has a high input and a high output resistance
B. It has a low input and a high output resistance
C. It has a high input and a low output resistance
D. It has a low input and a low output resistance

19. Proper biasing of a transistor amplifier, regardless of the circuit used, consists of

A. forward bias on the emitter-to-base junction and reverse bias on the collector-to-base junction.
B. reverse bias on the emitter-to-base junction and forward bias on the collector-to-base junction.
C. reverse bias on the emitter-to-base junction as well as on the collector-to-base junction.
D. forward bias on the emitter-to-base and on the collector-to-base junctions.

20. The circuit in figure 3-27 shows a PNP transistor properly biased using a single battery. Proper biasing consists of

A. collector negative in respect to the base and the emitter positive in respect to the base.
B. collector positive in respect to the base and the base negative in respect to the emitter.
C. base positive in respect to the collector and the emitter negative in respect to the base.
D. collector positive in respect to the base and the emitter positive in respect to the base.

LESSON 4. BIAS STABILIZATION

MMS Subcourse Number 701..... Transistors and Semiconductors

Lesson Objective..... To provide the student with a general knowledge of voltage and current stabilization circuits using thermisters, semiconductor diodes, and transistors.

Credit Hours..... Two

TEXT

1. INTRODUCTION.

a. General. Bias is established for a transistor by determining the quiescent (no signal) value of collector voltage and emitter current. If the transistor must be operated over a wide range of external temperatures, the bias voltage and current must remain stable. Variations of the reverse bias collector current and the emitter-to-base junction resistance with temperature changes, reduce the stability of the circuit. External compensating circuits must be used to keep the operation of the transistor stabilized.

(1) Reverse-bias collector current (saturation). The saturation current varies from about zero to 10 degrees C to over 1 milliampere at 150 degrees C (figure 4-1). Notice that the saturation current is no problem at external temperatures below 10 degrees C. Saturation current in an NPN transistor consists of a flow of holes from the collector region to the base region. If external resistors connected to the base are high on ohmic value, holes (positive charges) will accumulate in the base region. A high base resistance reduces the base current, therefore fewer holes combine with electrons at the external circuit of the base. This will cause an increase of electrons flowing from the emitter into and through the base to the collector. Note that more of the positive charges in the base attract more electrons from the emitter. Collector current will then increase and raise the temperature at the collector-to-base junction. This will increase the saturation current. The cycle will continue until the transistor becomes inoperative, or destroys itself. This condition can be minimized by avoiding the use of high value resistors in the base lead. The same conditions exist for PNP operation, except that electrons and holes move in the opposite direction.

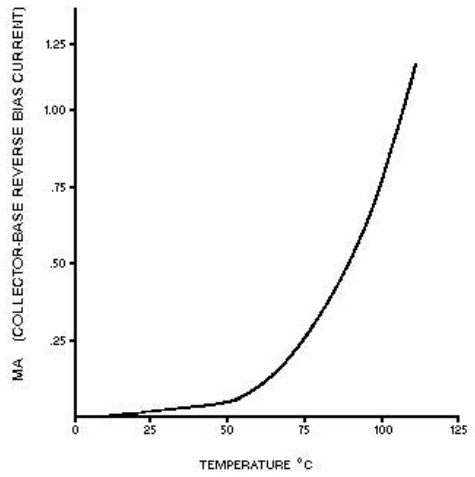


Figure 4-1. Variation of saturation current with temperature.

(2) Emitter-to-base junction resistance. In the previous example, if only the reverse current caused the collector current variations with temperature, then the collector current should be constant below 10 degrees C. However it is found that the collector current does vary with temperature even when the reverse current is close to zero. This variation is caused by the decrease in the emitter-to-base junction resistance when the temperature is increased. Junction resistance is an inverse function of temperature; when temperature increases junction resistance decreases and vice versa. This reaction to temperature changes is called a negative temperature coefficient of resistance.

(a) One method of reducing the effect of negative temperature coefficient of the junction is to use a swamping resistor (large value resistor) in the emitter lead. The resistance of the junction is then many times smaller in value than the emitter resistor. In effect, any variation of the emitter-to-base junction resistance is a small percentage of the total resistance of the emitter circuit. The name-swamping resistor is used because the external resistor is said to swamp or overcome the variations of the junction resistance.

(b) Another method of reducing the effect of negative temperature coefficient (sometimes called thermal runaway) is to reduce the emitter-to-base forward bias as the temperature increases. Conversely, if the temperature decreases, the emitter-to-base forward bias should be increased.

b. Base Resistance and Emitter Resistance. The effect on the stability of the collector current by various combinations of base and emitter resistance values is shown in the graph in figure 4-2. The ideal current is represented by the dashed line. Notice that the collector current is very unstable when the emitter and base resistances are both zero (curve AA). There is a slight improvement in stability when the base resistance is approximately 40 kilohms and the emitter resistance is zero (curve BB). The collector current is most stable when the emitter resistance is greater than zero (about 2 kilohms), and the base resistance is zero (curve CC).

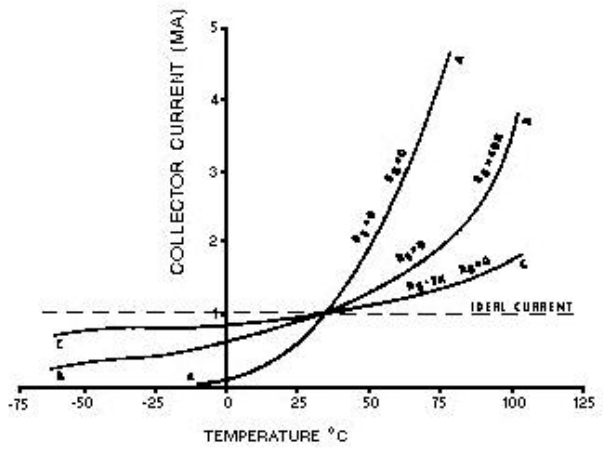


Figure 4-2. Collector current variations.

2. STABILIZING CIRCUITS THAT USE THERMISTORS.

a. General. It has been established that the bias current of the transistor is sensitive to external temperature changes. Specifically, emitter current increases with an increase in temperature. However, emitter current can be stabilized by using external circuits with temperature-sensitivity elements. One such element is the thermistor, which is the contraction of the words thermal and resistor. The thermistor has a negative temperature coefficient of resistance; its resistance decreases as temperature increases.

b. Emitter Voltage Control. A circuit that uses a thermistor to control emitter bias voltage and, thus, the emitter current, is shown in figure 4-3. The thermistor reacts to changes in temperature and causes the emitter bias voltage to change. In turn, the changes in emitter bias counteract the effects of the external temperature changes on emitter current.

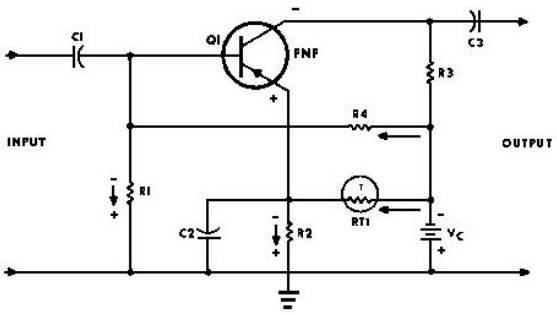


Figure 4-3. Thermistor control of emitter bias voltage.

(1) The circuit contains two voltage dividers: one consists of resistors R4 and R1; and the other consists of resistor R2 and thermistor RT1. Voltage divider R4-R1 applies a portion of the collector battery voltage (VC) to the base of the transistor. Forward bias voltage for the base is developed across resistor R1. Reverse bias voltage for the emitter is developed across resistor R2. The forward bias voltage applied to the base is greater than the reverse bias applied to the emitter. At a given (normal) external temperature, the resultant base-to-emitter bias is in the forward direction. Collector current flows at a steady, predetermined value with no input signal applied.

(2) Ordinarily, when the temperature rises, the collector current would tend to increase. However, as the temperature increases, the resistance of the thermistor decreases. This causes more current through voltage divider RT1-R2 and increases the negative potential at the emitter (top of R2 becomes more negative). This action, in turn, increases the reverse bias applied to the emitter and, in effect, decreases the resultant emitter-to-base forward bias. As a result the collector current does not increase when the temperature rises.

(3) A drop in the external temperature will reverse the action of the thermistor and prevent a decrease in collector current. The resistance of the thermistor increases and causes a less negative potential at the top of R2. This action increases the emitter-to-base forward bias and causes the transistor to conduct more. Thus, the thermistor compensates for both increases and decreases in the external temperature. Current in the transistor amplifier is kept at a steady reference level and signals are not distorted in the amplification process.

(4) Other parts in the amplifier circuit are used as follows. Capacitor C1 blocks the dc voltage of the previous stage and applies the input signal into the base circuit. Capacitor C2 bypasses signal variations from the emitter. Resistor R3 is the collector load resistor and develops the output signal. Capacitor C3 blocks the dc collector voltage from affecting the next stage and also couples the signal output.

c. Base Voltage Control. Another method of stabilizing a transistor against external temperature changes is to vary the base voltage to control emitter current.

(1) The base voltage control circuit (figure 4-4) has a voltage divider consisting of resistor R1 and thermistor RT1. The voltage divider applies a portion of the collector battery voltage (VC) to the base circuit. Current through the voltage divider is indicated by the direction of the arrows. The thermistor develops a portion of the voltage, with polarity as shown, and forward biases the emitter-to-base junction.

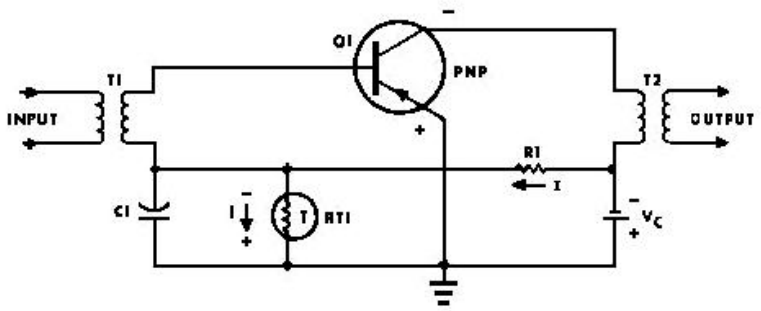


Figure 4-4. Thermistor control of base bias voltage.

(2) If the external temperature rises, the emitter current will also tend to rise. However, the resistance of the thermistor decreases with a rise in temperature and more current will flow through the voltage divider and cause R1 to drop a greater voltage. The voltage dropped across the thermistor is then less and reduces the emitter-to-base forward bias. Thus, the emitter current decreases in proportion to the increase in temperature. The opposite actions occur when the external temperature decreases.

(3) In the circuit of figure 4-4, transformer T1 applies the input signal to the base-emitter circuit. Capacitor C1 bypasses signal variations around the thermistor. The primary winding of transformer T2 is the collector load, and develops the output signal.

d. Thermistor Limitations. The ability of a thermistor to control the changes of collector current against variations in temperature is shown in figure 4-5. By comparing the two curves notice that there is an improvement in stability of the thermistor-controlled circuit. The curve for a thermistor stabilized circuit approaches the theoretical ideal current. However, thermistor stabilization achieves ideal current at only three points: A, B, and C. Since the thermistor is constructed of 3 material different from that of the transistor, it does not change resistance in exact proportion to the emitter current change. Therefore "tracking" is not very good and true compensation occurs at only a few points along the ideal current curve. In this respect, better stabilization can be obtained from semiconductor diode and transistor stabilizing circuits. This is explained below.

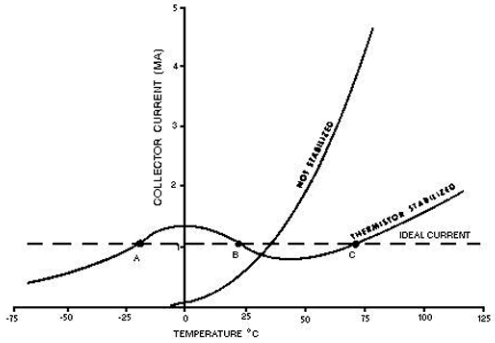


Figure 4-5. Non-stabilized and thermistor-stabilized graph.

3. STABILIZING CIRCUITS THAT USE SEMICONDUCTOR DIODES.

a. General. Semiconductor (junction) diodes are similar to thermistors in that they have a negative coefficient of resistance. It doesn't matter if the junction is reverse or forward biased, the diode retains the negative coefficient of resistance characteristic. Semiconductor diodes are also temperature sensitive: external temperature changes affect the bias current and the resistance of the PN junction. So semiconductor diodes can be used in transistor stabilizing circuits just as thermistors are used. However, there is one advantage in using semiconductor diodes: they are made of the same material as transistors. This permits the semiconductor diode to respond to temperature changes exactly like the transistor does something a thermistor cannot do. As a result, better stabilization of transistor collector current is attained over a wide range of temperature changes by using semiconductor diodes.

b. Forward Biased Single-Diode Stabilizing Circuits. Junction diode CR1 in the circuit in figure 4-6 is being used as a temperature-sensitive element. Its purpose in the circuit is to compensate for changes in emitter-to-base junction resistance caused by changes in the external temperature.

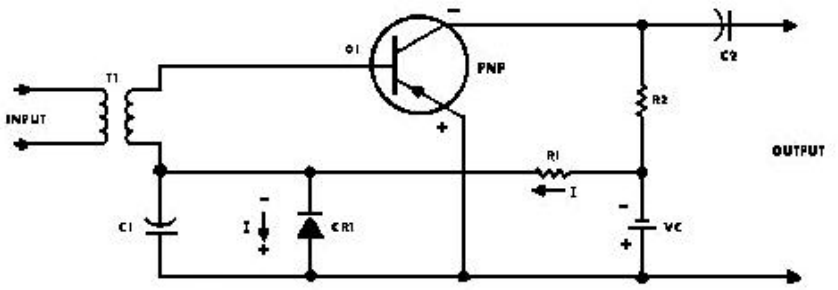


Figure 4-6. Single junction diode temperature compensating (emitter-base) circuit.

(1) Consider the voltage divider consisting of resistor R1 and junction diode CR1. The current (1) through the voltage divider flows in the direction shown, and develops a voltage across diode CR1 with polarity as indicated. This voltage forward biases the base-to-emitter junction. If the external temperature increases the collector current would tend to increase. However, an increase in temperature decreases the resistance of diode CR1 and causes more current through the voltage divider. As a result, the voltage drop across resistor R1 increases. The voltage drop across diode CR1 is correspondingly decreased, thereby reducing the forward bias and the collector current.

(2) The effectiveness of this circuit in stabilizing collector current against temperature changes is indicated by curve BB of figure 4-7. Compare this curve with curve AA in which the transistor is not stabilized, and with the ideal current curve. Curve BB shows a marked improvement in the collector current stability for temperatures below 50 degrees C. This shows that the resistance of the junction diode changes (tracks) to compensate for changes in the emitter-to-base junction resistance of the transistor as the external temperature changes. The sharp increase in collector current (curve BB, figure 4-7) at temperatures above 50 degrees C, indicates that the single junction diode CR1 does not compensate for the increase in saturation current. Saturation current (collector-to-base reverse bias current) flows out of the base through the secondary winding of T1, through CR1, to the battery and back to the collector. Because saturation current is very small, it causes no appreciable voltage drop across CR1. To compensate for the increase in saturation current, double-diode stabilization is required.

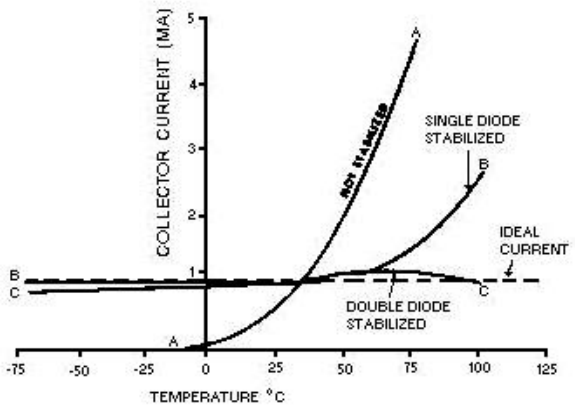


Figure 4-7. Variation of collector current for non-stabilized and stabilized circuits.

c. Double-Diode Stabilization. As the name implies, double-diode stabilization uses two junction diodes as temperature-sensitive elements (figure 4-8). Diode CR1 compensates for the temperature variations that affect the emitter-to-base junction resistance, and CR2 compensates for the temperature variations that affect saturation current. The circuit is similar to that in figure 4-6, except that resistor R3 and diode CR2 (reverse biased) have been added. Resistor R1 and diode CR1 (forward biased) compensate for changes in emitter-to-base junction resistance at temperature changes below 50 degrees C.

(1) Reverse biased junction diode CR2 (figure 4-8) is considered to be an open circuit at room temperature or below. Above room temperature, reverse bias current (Is) flows through CR2 in the direction indicated. CR2 is selected so that its reverse bias current is greater than the saturation current (ICBO) of the transistor. Reverse bias current (Is) through CR2 consists of saturation current plus the current through R1.

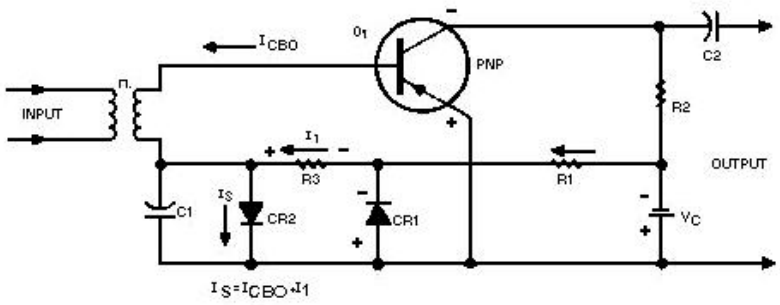


Figure 4-8. Double-diode temperature compensating (emitter-base) circuit.

(2) As the temperature continues to increase, saturation current, reverse bias current, and current I1 increase. Current I1 produces a voltage drop across R3 (polarity as indicated), and reduces the forward bias set up by CR1 and R1. The net effect at higher than room temperature is to reduce (stabilize) the total collector current by reducing the emitter-to-base forward bias. The effectiveness of this circuit in stabilizing collector current at high and low temperatures is indicated by curve CC of figure 4-7.

d. Reverse Biased Single-Diode Stabilization. Transistor amplifiers can be stabilized by a reverse biased single junction semiconductor diode. This circuit is used when resistance-capacitance coupling is used as the input from the previous stage.

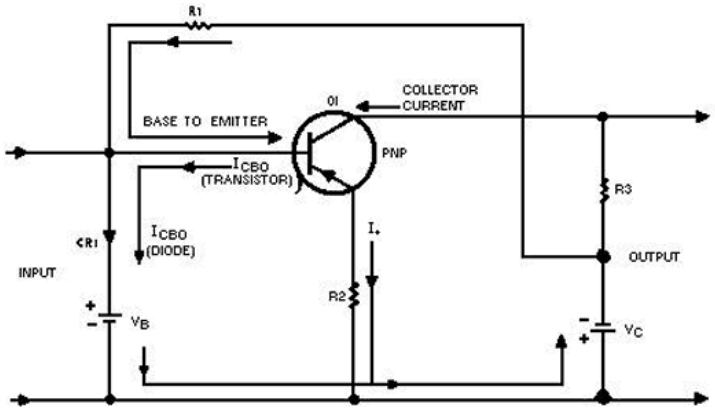


Figure 4-9. Reverse biased junction diode compensating circuit.

(1) In the circuit shown in figure 4-9, reverse biased junction diode CR1 is the temperature sensitive element. This circuit provides two separate paths for base current. The base-to emitter current flows from the base region to the emitter, through resistor R2, collector battery (Vc), and resistor R1 back to the base. Saturation current (IcBO) flows from the base lead through CR1, base battery (VB), collector battery (Vc), through resistor R3, to the collector region, and to the base region. The diode is selected so that its reverse bias current equals that of the transistor over a wide range of temperatures.

(2) As temperature increases, saturation current of the transistor increases. Saturation current of the diode also increases by an equal amount. Saturation current of the diode opposes the saturation current of the transistor and prevents an increase in the transistor emitter current (Ie). Thus CR1 acts as a gate, opening wider to accommodate the increase in saturation current of the transistor.

4. STABILIZING CIRCUITS THAT USE TRANSISTORS.

a. Emitter-to-Base Voltage Stabilization. The emitter-base junction of a transistor has a negative temperature coefficient of resistance similar to that of a PN junction diode. It is then possible to use variations of the emitter-base junction resistance of one transistor to control the emitter-base bias of a second transistor (figure 4-10). In the figure, the emitter-base voltage of transistor Q1 is used to bias the emitter-base junction of transistor Q2. Assuming zero resistance in the secondary winding of transformer T2, the base of transistor Q2 has a direct connection to the emitter of transistor Q1. Battery VE provides emitter-to-base forward bias for transistors Q1 and Q2. Transistor Q1 is temperature stabilized by use of the high-value swamping resistor R1 in the emitter lead. Resistor R1 maintains a relatively constant emitter current in transistor Q1.

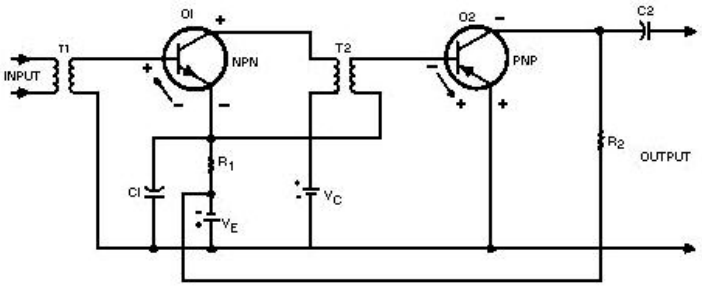


Figure 4-10. Two-transistor temperature stabilizing circuit.

(1) As the external temperature increases, the base-to-emitter junction resistance of Q1 decreases. Because the current through the junction remains constant, the voltage drops across the junction decreases. A decrease in this voltage represents a decrease in the forward bias of Q2. Thus, the tendency of the Q2 collector current to increase with an increase in the external temperature is offset. If a curve of the Q2 collector current versus temperature were plotted, it would be similar to the double-diode stabilization curve (curve CCC, figure 4-7).

(2) In the circuit, battery VE also supplies collector voltage for Q2. Capacitor C1 bypasses signal variations around resistor R1 and battery VE and battery VC supplies the collector voltage for Q1.

b. Emitter-to-Collector Current Stabilization. A method of temperature stabilizing the emitter-to-collector current of one transistor by using the stabilized emitter-to-collector current of another transistor is shown in figure 4-11. The collector current of Q1 is stabilized by use of a high value swamping resistor R2. Resistor R1 is selected so that its value is low; it limits saturation current carriers in the base region.

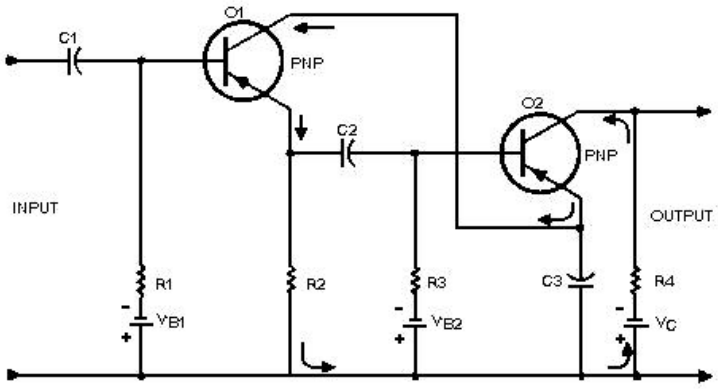


Figure 4-11. Collector current temperature stabilizing circuit.

(1) The stabilized collector current of Q1 flows through Q2. Note that the collector of Q1 is connected to the emitter of Q2. The current direction is indicated by the arrows. Electrons that flow from the emitter of Q1, travel through R2, VC, R4, collector-to-emitter of Q2, and back to the collector of Q1. Q1, in effect, is stabilizing Q2.

(2) In the circuit, Q1 is used as a common collector amplifier and Q2 is used as a common emitter amplifier. R2 is a load resistor for Q1. The collector of Q1 gets its voltage from battery VC, through Q2 and R4.

c. Bias Variation With Collector Current. Figure 4-12 shows two stages of a direct coupled amplifier. An increase in collector current caused by a temperature rise in transistor Q1 will reduce the forward bias for transistor Q2.

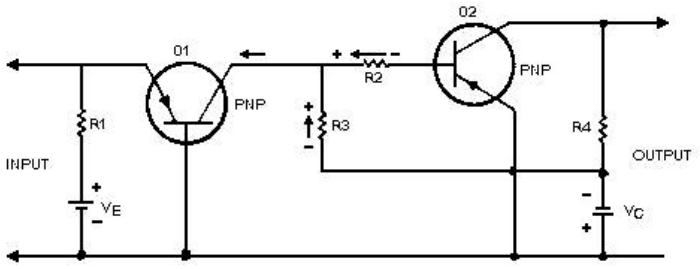


Figure 4-12. Two-stage temperature stabilized direct coupled amplifier.

(1) Assume that the collector current of Q1 increases due to a rise in external temperature. The increase in collector current is shown by the direction of the arrows. A portion of this increase flows through resistor R3, with polarities as indicated. Another portion of the increase flows through R2 and develops a voltage as indicated. The voltages across R2 and R3 of importance in this description are those voltages used to compensate for increases in the collector current of Q1 caused by a rise in temperature.

(2) The emitter-to-base forward bias of Q2 is equal to the sum of the voltages across R2, R3, and collector battery VC. The voltage across R3 aids the forward bias while the voltage across R2 opposes the forward bias. R2 and R3 are selected so that the voltage drop across R2 is larger than R3. In effect when the collector current of Q1 rises, due to a rise in temperature, the forward bias of Q2 is decreased. This action limits the tendency of the collector current of Q2 to rise when there is an increase in temperature.

5. VOLTAGE STABILIZATION.

a. Voltage Stabilized Transistor Amplifier. The Zener diode (CR1) in the circuit in figure 4-13 has a positive coefficient of temperature and is used for collector voltage stabilization. As the external temperature rises, the resistance of the Zener diode increases. Current (I2) from the collector battery VC divides into Zener diode current I1 and collector current IC. When the collector current of Q1 increases due to the increase of temperature, current I1 decreases by the same amount. The resistance of CR1 increases causing current through CR1 to decrease. The current (I2) therefore remains the same, and the voltage across R2 remains constant. The voltage applied to the collector (battery voltage less drop across R2) also will remain constant. To avoid bypassing R2 by the low ac resistance (as low as 5 ohms) of Zener diode CR1, a high impedance coil (L1) is placed in series with the diode.

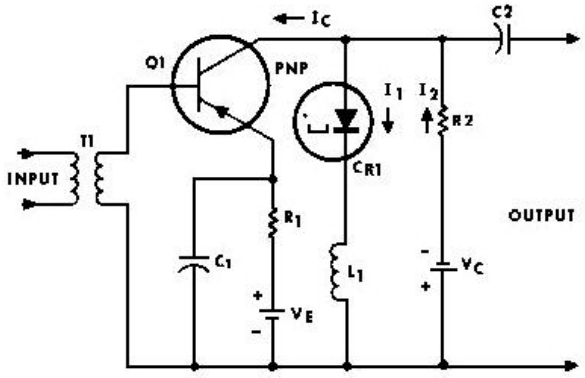


Figure 4-13. Zener diode collector voltage stabilization.

b. Surge Protection by Junction Diode. In transistor amplifiers using input and output transformers, if an excessive emitter-to-collector voltage occurs when the normally forward biased base-to-emitter junction is suddenly reverse biased, internal oscillations may occur. The oscillations can destroy the transistor. A junction diode can be used to protect the amplifier (figure 4-14) against sudden voltage surges.

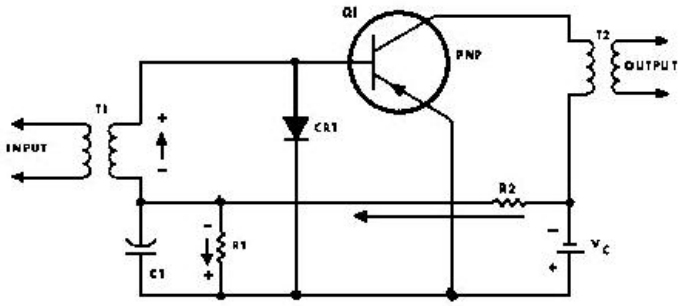


Figure 4-14. Control of base-emitter circuit.

(1) If the input signal suddenly stops, or if excessive noise drives the base-to-emitter junction into a reverse biased condition, the collector current is quickly cut off. The field surrounding transformer T2 collapses and produces a high emitter-to-collector voltage. This condition causes strong oscillations in the transistor which can destroy it. To prevent this condition, a junction diode is used to prevent the base-to-emitter junction from being reverse biased. The voltage divider consisting of R1 and R2 forward biases the base-to-emitter junction of Q1 and reverse biases diode CR1. Under normal operating conditions CR1 is considered an open circuit.

(2) A strong surge voltage may occur at the input (assume polarity as indicated). If the surge voltage is greater than the voltage across R1, diode CR1 becomes forward biased and conducts. Although when CR1 conducts, a negligible voltage appears across it, its action prevents the base-to-emitter junction of Q1 from becoming reverse biased.

MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS

EXERCISES FOR LESSON 4

1. Reverse-bias collector current refers to the saturation current that flows through the reverse-biased collector-base junction. This flow begins and increases with temperature above 10 degrees C. We avoid the resulting accumulation of charge in the base region by providing a leakage path through the external circuit from base to collector. This can be done by avoiding the use of a

   A. low-value resistor in the collector lead.
   B. high-value resistor in the base lead.
   C. low-value resistor in the base lead.
   D. low-value inductor in the base lead.

2. Emitter-to-base junction resistance refers to the resistance at the forward-biased emitter-base junction. The resistance at this junction decreases the temperature is increased. This reaction to temperature change is called a

   A. reverse temperature coefficient of resistance.
   B. positive temperature coefficient of resistance.
   C. negative temperature coefficient of resistance.
   D. decreasing temperature coefficient of resistance.

3. To neutralize the effect of temperature variations in a transistor, we use thermistors in the external circuit. What is unique about the thermistor?

   A. It keeps a constant temperature
   B. Its resistance decreases as temperature decreases
   C. Its resistance decreases as temperature increases
   D. It keeps a constant resistance even with temperature changes

4. Used as all emitter voltage control, the thermistor increases the reverse bias on the emitter resistor when the temperature increases. This in turn, will decrease the

   A. forward bias of the base-emitter junction.
   B. reverse bias of the base-emitter junction.
   C. forward bias of the base-collector junction.
   D. reverse bias of the base-collector junction.

5. Why is better tracking achieved over a wide range of temperatures when junction diodes are used in place of thermistors?

   A. The diode responds to temperature change as the thermistor does
   B. The diode has a negative temperature coefficient
   C. The diode maintains a constant current
   D. The diode can tolerate more heat

6. Double-diode stabilization uses two junction diodes as temperature-sensitive elements. In figure 4-8, diode CR2 compensates for the temperature variations that affect

   A. the emitter-to-base junction.
   B. the saturation current.
   C. thermal runaway.
   D. diode CR1.

7. In the two-transistor temperature stabilization circuit of figure 4-10, the emitter-base bias voltage of transistor Q1 is also used as the

   A. collector voltage for Q2.
   B. bias voltage for the base-collector junction of Q1.
   C. bias voltage for the base-collector junction of Q2.
   D. bias voltage for the emitter-base junction of Q2.

8. A Zener diode has a positive coefficient of temperature and is used for collector voltage stabilization in the circuit of figure 4-13. How does the collector current and the Zener diode resistance vary as the temperature rises?

	Collector Current	Zener Resistance
A.	Increases	Increases
B.	Decreases	Decreases
C.	Increases	Decreases
D.	Decreases	Increases

9. In figure 4-3, forward bias voltage is developed across

   A. R2.
   B. RT1.
   C. R1.
   D. R3.

10. In figure 4-2, which curve shows the most unstable collector current?

A. AA
B. BB
C. CC
D. Dotted line

11. CR1 in figure 4-6 NEVER

A. is part of a voltage divider with R1.
B. biases the base-to-emitter junction.
C. compensates for an increase in saturation current.
D. increases resistance as temperature increases.

12. When is a reverse biased single-diode used to stabilize a transistor amplifier circuit?

A. Only with a high gain amplifier
B. If saturation is not of great importance
C. Only when external temperature is below 10 degrees C
D. When resistance-capacitance coupling is used as an input from a previous stage

13. What is the main purpose of junction diode CR1 in figure 4-14?

A. Provide emitter to base bias
B. Increase forward bias of transistor Q1
C. Protect amplifier against sudden voltage changes
D. Insure capability of circuit to oscillate

14. An increase in collector current in transistor Q1 in figure 4-12 (caused by a temperature rise in Q1) will

A. increase the forward bias of Q2.
B. reduce the forward bias of Q2.
C. have no affect on bias of Q2.
D. increase forward bias on Q1.

15. What component in figure 4-11 is used to stabilize collector current of Q1?

A. C3
B. R1
C. R2
D. R3

LESSON 5. TRANSISTOR AMPLIFIERS

MMS Subcourse Number 701.....	**Transistors and Semiconductors**
Lesson Objective.....	**To provide the student with general knowledge of transistor amplifiers to include coupling networks, phase inverters, power amplifiers, and high and low frequency compensation circuits.**
Credit Hours.....	**Three**

TEXT

1. INTRODUCTION.

a. General.

(1) Audio amplifiers are used in equipment such as public address systems, sound recorders, sound reproducers, and radio and television sets. The frequencies of the audio signals amplified range from 10 to 20,000 Hz.

(2) The input circuit of a transistor amplifier may draw current from either the input device or the previous stage. In this respect, each transistor amplifier is considered as either a current or a power amplifier operating at a current or a power level higher than the previous stage and lower than the following stage. Preamplifiers usually operate at power levels measured in micromicrowatts, or microwatts. Driver stages usually operate at power levels measured in milliwatts. Power stages usually operate at power levels measured in hundreds of milliwatts or in watts. These power levels are only approximate; the equipment in which these stages are used determines the power levels of the preamplifier, the driver, and the power stage.

b. Classification of Amplifiers. Transistor amplifiers can be operated class A, class B, class AB, or class C.

(1) Class A. Class A amplifiers are operated on the linear portion of the collector current characteristic curve. The transistor amplifier is biased so that collector current flows continuously during the complete input signal cycle. It also flows without an input signal (operating point). Audio amplifiers, operated class A, may be used in single-ended or in push-pull applications.

(2) Class B. Class B amplifiers are biased for collector current cutoff. Collector current cutoff means that collector current will flow only during one half cycle of the input signal. Class B audio amplifiers must be operated push-pull (covered later in this lesson) to avoid severe signal distortion.

(3) Class AB. A transistor amplifier that operates between class A and class B is called a class AB amplifier. Collector current flows for more than half a cycle but less than the entire input signal cycle.

(4) Class C. Class C amplifiers are biased so that collector current flows for less than one half of a cycle of the input signal. Class C amplifiers are generally used as radio frequency amplifiers (not as audio amplifiers) due to severe signal distortion. They are used where a large power output is desired.

2. COUPLING NETWORKS

a. General. Coupling a signal from one transistor stage to another is accomplished by several different methods: by resistance-capacitance coupling (A, figure 5-1); by transformer coupling (B, figure 5-1); by impedance coupling (C, figure 5-1); and by direct coupling (D, figure 5-1). Current, voltage, and power gains of transistor stages are usually made adjustable by variable resistors in the coupling networks. These variable resistors are usually referred to as gain controls. At audio frequencies, the gain control is also called the volume control.

b. Resistance-Capacitance (RC) Coupled Amplifiers. The resistance-capacitance network (dashed line, A, figure 5-1) between two transistor stages consists of a collector load resistor (R1), a dc blocking capacitor (C1), and a dc return resistor (R2) as the input to the second stage.

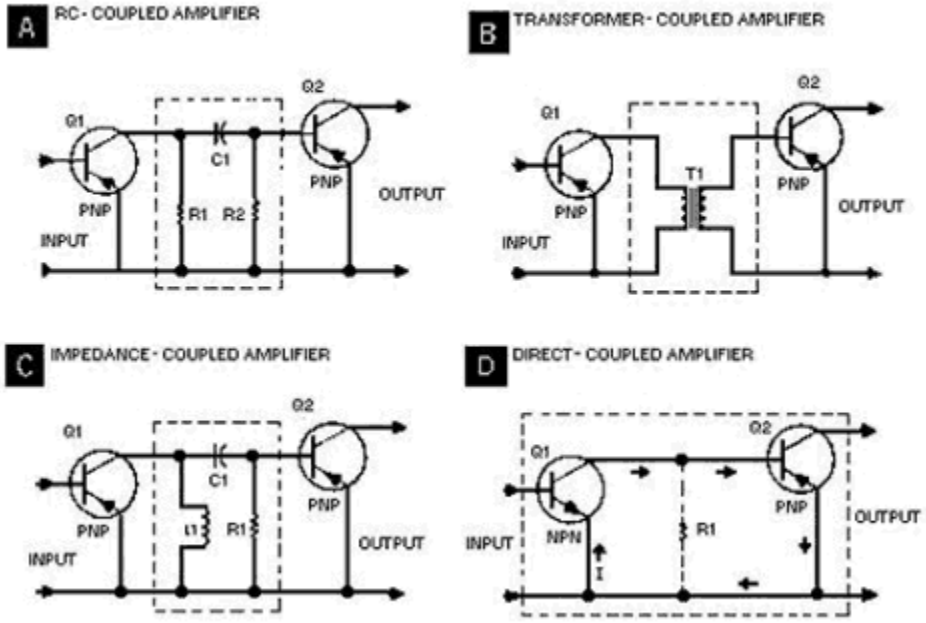


Figure 5-1. Interstage coupling networks.

(1) Due to the dissipation of dc power in the collector load resistor, the efficiency (rate of ac power output to dc power delivered to stage) of the RC coupled amplifier is low. The dc blocking capacitor prevents the dc voltage of the collector of the first stage from appearing on the input terminal of the second stage. To prevent a large signal voltage drop across the dc blocking capacitor, the reactance of the capacitor must be small compared to the input resistance of the following stage with which it is in

series. Since the input resistance of the following stage is low (usually lower than 1000 ohms), the capacitance value must be high. However, because of the low voltages used, the physical size of the capacitor can be kept small.

(2) The resistance of the dc return resistor is usually 7 to 15 times the input resistance of the second stage. This ratio is selected to prevent shunting the signal current around the input circuit of the second stage.

(3) Resistance-capacitance coupling is used extensively with junction transistors. High gain, economy of circuit components, and small size can be achieved with RC coupling. By using emitter swamping resistors and self-bias, good temperature stability can also be achieved. This form of coupling is used in audio amplifiers, such as low-level, low-noise preamplifiers up to high-level amplifiers for power stages.

c. Transformer Coupled Amplifiers. Interstage coupling by a transformer is shown in B, figure 5-1. The primary winding of transformer T1 is the collector load of the first stage. The secondary winding of transformer T1 introduces the ac signal to the base and also acts as the base dc return path. The very low resistance in the base path aids temperature stabilization of the dc operating point. With a swamping resistor in the emitter lead, the current stability factor is ideal.

(1) Since there is no collector load resistor to dissipate power, the power efficiency of the transformer coupled amplifier approaches the theoretical maximum of 50 percent. For this reason, the transformer coupled amplifier is used extensively in portable equipment where battery power is used.

(2) The frequency response (ability to pass many different frequencies) of a transformer coupled stage is not as good as that of a resistance-capacitance coupled stage. In addition to poor frequency response, transformers are more expensive, heavier, and larger in size compared to resistors and capacitors used for coupling. Use of transformers is normally confined to those applications requiring high power efficiency and high output power.

d. Impedance Coupled Amplifier. An impedance coupled amplifier is one in which either or both resistors of a resistance-capacitance coupled amplifier are replaced by inductors (C, figure 5-1). The collector load resistor may be replaced by an inductor. This provides high power efficiency, since the dc power loss is eliminated. The frequency response of the impedance coupled amplifier is better than that of the transformer coupled amplifier, but not as good as that of the resistance-capacitance coupled amplifier.

e. Direct Coupled Amplifier. The direct coupled amplifier is used for amplification of dc signals and for amplification of very low frequencies. In D, figure 5-1, an NPN transistor is shown connected directly to a PNP transistor. The direction of current is shown by the arrows. If the collector current of the first stage is greater than the base current of the second stage, then a collector load resistor (R1) must be used. Since there are very few components required, maximum economy can be achieved. However there are several disadvantages to this coupling method. The number of stages that can be directly coupled is limited. In addition, temperature variation of bias current in one stage is amplified in all stages, causing severe temperature instability.

f. Volume Control.

(1) A volume control must be arranged so that it does not introduce noise into the circuit. To do this, we must avoid having large amounts of current through the control. Also, the volume control circuit should let us vary the signal level of the audio amplifier from zero to maximum.

(2) Figure 5-2 shows that the collector signal output current (io) divided at the movable arm to supply varying amounts of input current (i in) to the base-to-emitter circuit of Q2. Since the base-to-emitter junction resistance is extremely small compared to the resistance of R2, output current (IO) is equal to the input current (i in) when the variable arm is in the upper position. In this position, the entire signal is applied to the base of Q2, and the control permits maximum gain. On the other hand, when the variable arm is in its lowest position, there is zero gain; there is no input signal developed across R2.

(3) A volume control is operated every time the sound on a radio or television set is increased or decreased. In order to make the sound louder the volume control is turned clockwise. This moves the adjustable arm upward on the figure so that more of the signal is developed across the variable resistor. In order to decrease the sound the volume control is turned counterclockwise. The adjustable arm moves down and less (or none) of the signal voltage is developed across the resistor. In the first case more resistance and more signal voltage is applied to Q2. In the second case less resistance and less signal voltage is applied to Q2.

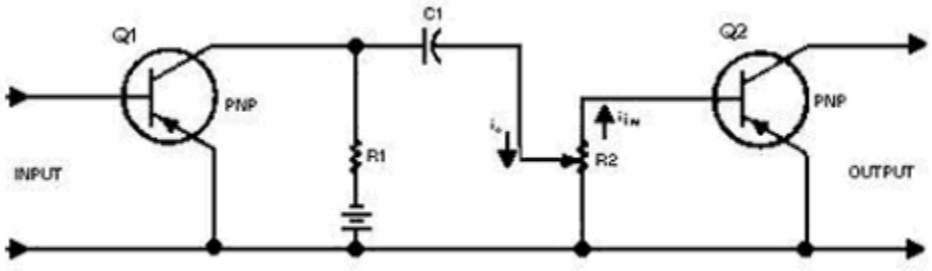


Figure 5-2. Volume control used as a voltage or current divider.

3. PHASE INVERTERS USED AS DRIVER STAGES.

a. General.

(1) The purpose of an audio amplifying section is to take a weak audio signal and build it up until it has enough power to perform some useful function. Regardless of whether the audio section contains few or many amplifiers, the function of each stage is to increase the signal level.

(2) The last stage of an audio amplifier section is called the power stage. The driver stage is the term used to describe the amplifier that supplies the "driving" or input signal to the final or power amplifier stage. In cases where the power amplifier is a push-pull circuit, it is necessary to use a phase splitter or phase inverter as the driver stage. The purpose of the

phase inverter is to supply two equal amplitude output signals, out of phase 180 degrees.

b. Transformer Phase Splitter.

(1) Figure 5-3 shows an audio driver stage with a transformer phase splitter. The audio signal is coupled from volume control R1 to the input of the driver stage by capacitor C1. Resistors R2 and R3 establish a fixed base bias, while R4 and C2 provide emitter bias. As the input signal goes through its positive alternation (PNP operation), the forward bias of Q1 decreases with a resultant decrease in transistor conduction. Collector current from the collector battery through the primary of T1 decreases. The collector voltage (terminal 1 of the primary) becomes more negative. Through transformer action, terminal 3 of T1 goes positive with respect to the center tap of the secondary (terminal 4). Terminal 5 of T1 goes negative with respect to terminal 4.

(2) When the input signal goes through its negative alternation, the forward bias of Q1 is increased. Transistor conduction increases and terminal 1 of T1 goes in the positive direction (less negative). Through transformer action, terminal 3 of T1 produces a negative output at this time, while a positive output appears at terminal 5.

(3) Notice that the secondary output signals are of equal amplitude, but are 180 degrees out of phase with each other. These two signals can be used as the input to a push-pull amplifier. Although the transformer phase splitter is a simple means of developing the required input signals, there are other ways with better economy, size, and weight characteristics to get the same results.

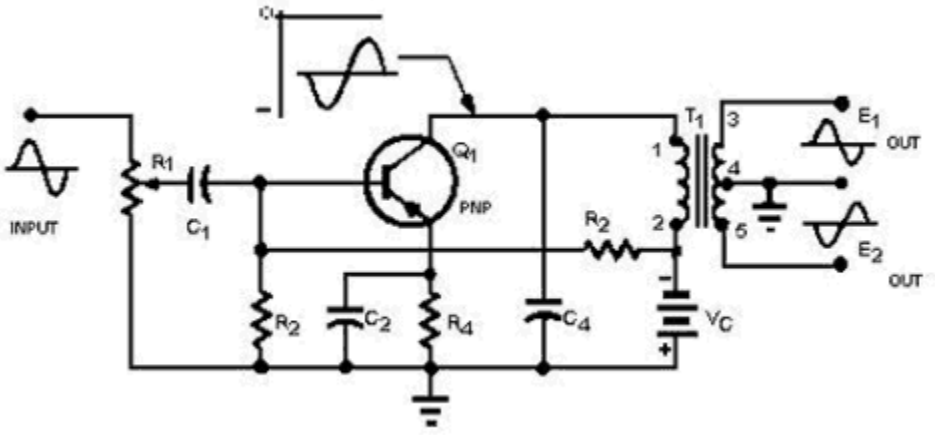


Figure 5-3. Driver stage with transformer phase splitter.

c. Split-Load Phase Inverter. A split-load phase inverter is shown in figure 5-4. It supplies the two input signals to a push-pull power amplifier circuit without using a transformer.

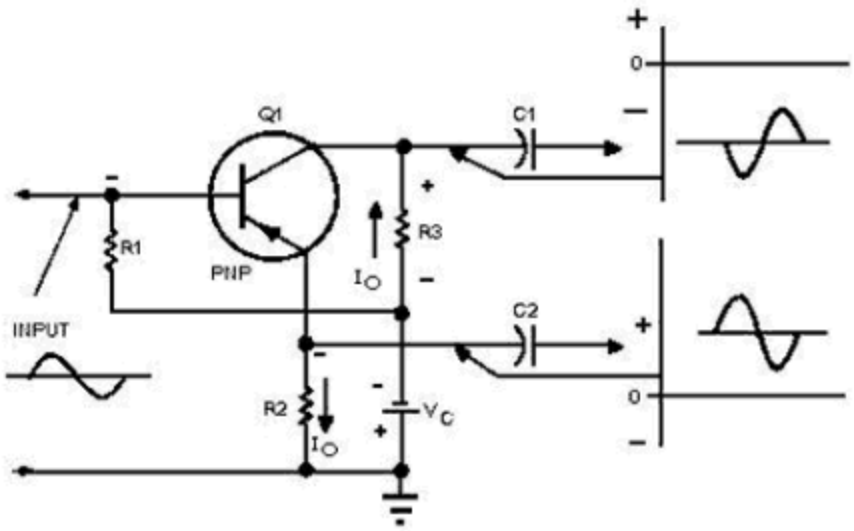


Figure 5-4. Split-load phase inverter (one-stage).

(1) The output current of transistor Q1 flows through collector load resistor R3 and emitter load resistor R2, R2 and R3 are equal in value. Resistor R1 establishes the base bias voltage.

(a) When the input signal opposes the forward bias (base becomes more positive), the current through Q1 decreases. This decreased current causes the top of R3 to become more negative with respect to ground. The top of R2 becomes more positive with respect to ground (less current flows through R2).

(b) When the input signal aids the forward bias (base becomes more negative) the output current increases. The top of R3 becomes more positive with respect to ground. The top of R2 becomes more negative with respect to ground (more current flows through R2 increasing its voltage drop).

(c) These actions produce two output signals that are 180 degrees out of phase with each other.

(2) One problem exists in this circuit arrangement. Since the collector output impedance of Q1 is higher than its emitter output impedance, the two output signals will not be of the same voltage amplitude. This is overcome by adding resistor R4 (figure 5-5). The value of R4 is chosen so that its value and that of R2 (emitter output impedance) will balance the collector output impedance. The signal voltage loss across R4 is compensated for by also making R2 higher in value than R3.

(3) Note that emitter resistor R2 is unbypassed to allow signal variations to appear at the emitter. Because of the large negative feedback voltage developed across R2, a large signal input is required to drive the one-stage phase inverter. This disadvantage can be overcome by using a two-stage phase inverter circuit. In addition, a two-stage phase inverter provides more power output. This is important if the driver stage must feed a large amount of power to a higher level push-pull power output stage.

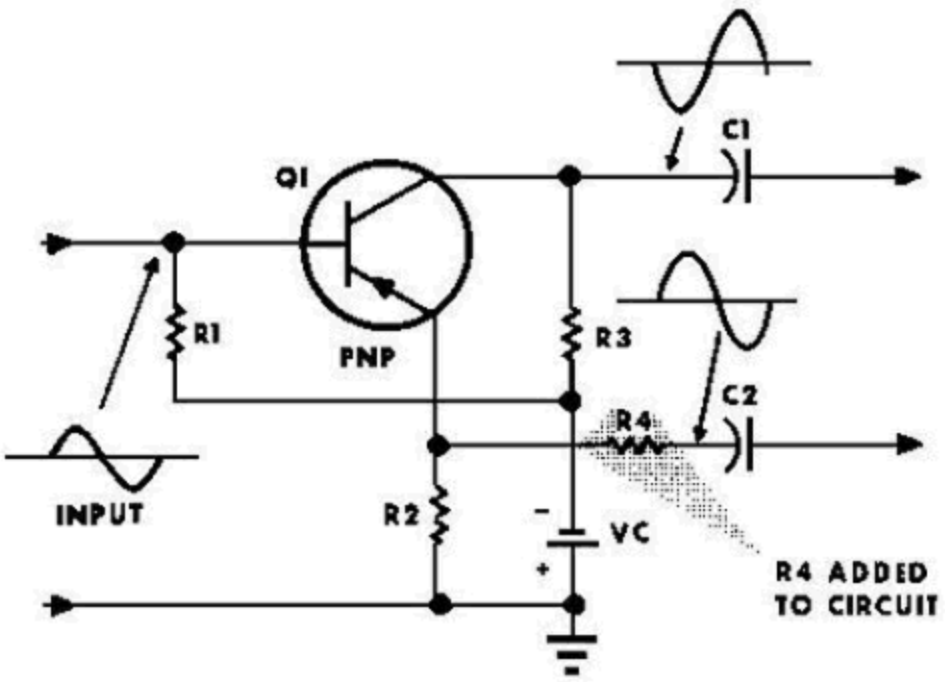


Figure 5-5. One-stage phase inverter with equalized output impedance.

d. Two-Stage Phase Inverter, Common Emitter Configuration.

(1) Figure 5-6 shows a two-stage phase inverter consisting of two identical common emitter circuits. Assume that the input signal drives the base of Q1 positive (positive input alternation). Due to the 180 degree phase reversal of a common emitter circuit, the collector of Q1 swings negative. This negative going signal is coupled to the base of Q2 through capacitor C2 and resistor R4. The signal is also coupled through C4 to one input circuit of a push-pull output stage. The negative going signal on the base of Q2 produces a positive going signal at the collector of Q2. This positive going signal is coupled through C5 to the other input circuit of the push-pull output stage. When the input signal swings in the negative direction, the outputs of Q1 and Q2 change direction.

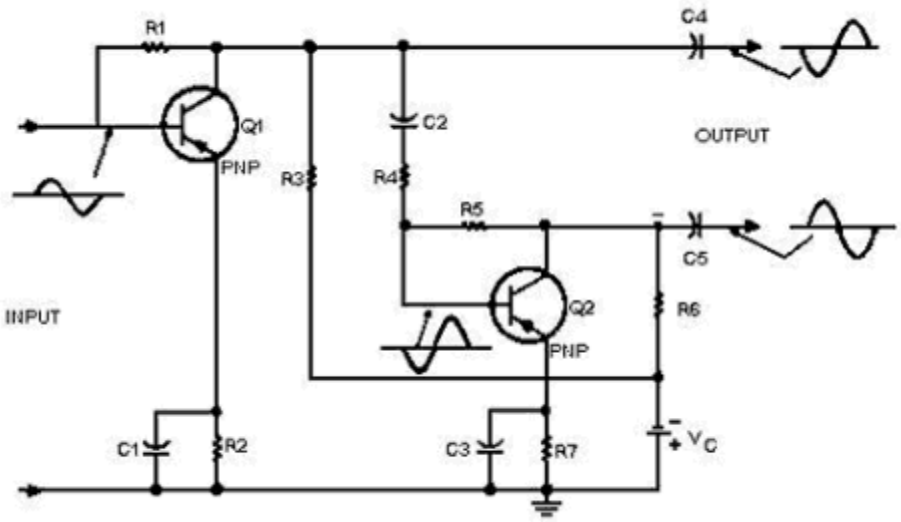


Figure 5-6. Two-stage phase inverter using two CE configurations.

(2) Resistor R1 provides base bias for transistor Q1. Collector load resistor R3 develops the output signal of Q1. Resistor R2 is the emitter swamping resistor and R5 provides base bias for Q2. Collector load resistor R6 develops the output signal of Q2 and R7 is its emitter swamping resistor. Since two identical common emitter circuits are being used, the impedances are equal for the two input circuits of the push-pull stage.

e. Two-Stage Phase Inverter, Common Emitter and Common Base Circuits.

(1) A two stage phase inverter with a common emitter and common base circuits is shown in figure 5-7. Assume that the input signal swings positive. Due to the 180 degree phase reversal of the common emitter, the collector of Q1 swings negative. The signal on the emitter will swing in the positive direction. Remember that a positive input to the base of Q1 cuts down the current through the transistor. Less current through R2 and the emitter voltage approaches the positive value of the collector-to-base battery. Q2 is a common base circuit; its input is applied to its emitter while the output is developed in the collector circuit. There is no phase reversal in this circuit.

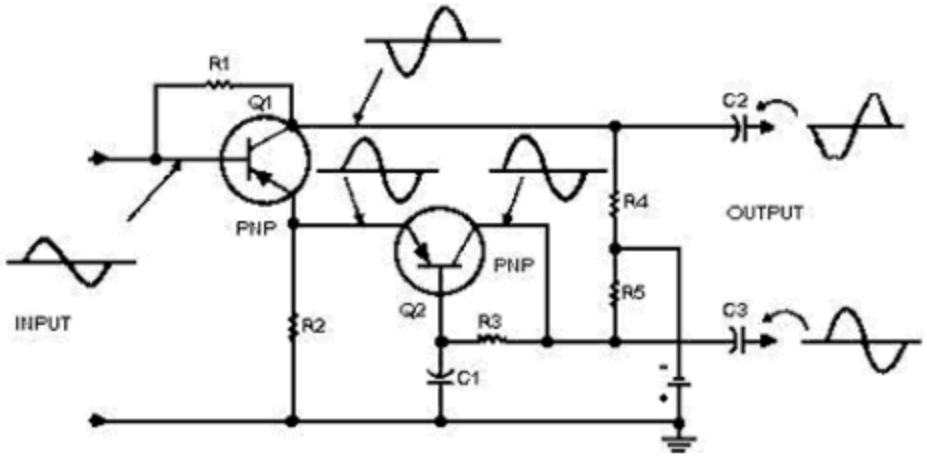


Figure 5-7. Two-stage phase inverter using a CE and CB configuration.

(2) The input to the emitter of Q2 is developed by the signal at the emitter of Q1. When the emitter of Q1 is swinging in the positive direction, a positive input is applied to Q2 and its output swings positive. Therefore, on the positive input alternation to the base of Q1, the collector of Q1 develops a negative-going signal, while the collector of Q2 develops a positive-going signal.

(3) The opposite conditions occur on the negative input alternation to the base of Q1. The collector of Q1 develops a positive going signal, while the emitter of Q1 develops a negative going signal. The input to the emitter of Q2 is the negative going signal from the emitter of Q1 and the collector output of W1 is a negative going signal. The output of Q1 and Q2 are of equal amplitude and 180 degrees out of phase with each other.

(4) The resistors and capacitors in the circuit are used as follows. R1 and R3 establish the base bias for Q1 and Q2, respectively. R4 is the collector load for Q1 and R5 is the collector load for Q2. R2 is the emitter resistor for Q1 and develops the signal applied to Q2. C1 places the base of Q2 at ac ground. C2 and C3 couple the two output signals to the input circuit of the push-pull stage.

4. POWER AMPLIFIERS.

a. General.

(1) It can be said that power amplifiers are not voltage amplifiers; or, that power amplifiers are current amplifiers. These are commonly used descriptions. However, consider a load such as a loud speaker that requires a certain amount of power (watts) to operate. Assume that a power source or power amplifier is designed that will provide enough output power to operate the load even without an input signal. But simply feeding power to the load is not enough; it has to be controlled power--in this case controlled to vary an audio rate so that sound comes out of the loudspeaker.

(2) The name "power amplifier" does not mean getting something for nothing; the fact is that when full (100 percent) power is applied to a power amplifier, from the source operating power (Vc), only about 50 percent of

useful power is received from the stage. It uses about 50 percent of the supplied power itself, to keep operating. This is a measure of the efficiency of the "power amplifier"; figures prove out to 50 percent efficiency. The percent of efficiency will vary depending on the kind of power amplifier used.

(3) There are two types of power amplifiers that will be discussed: the single-ended and the push-pull. Both types, because they are power amplifiers, are physically larger than voltage amplifiers and are usually mounted differently (on the chassis) to dissipate the heat that they generate. In addition, because the concern is with power rather than voltage gain, the value of load impedance is much lower than in other stages.

b. Single-Ended Power Amplifier. One requirement of any audio amplifier is minimum distortion of the input signal. Consequently, single-ended, audio power amplifiers must be operated class A. Figure 5-8 shows a simplified schematic of a single-ended, class A, power amplifier. All components perform basically the same as in any amplifier, except that the output of transistor Q1 is used to drive or operate a loud-speaker. Resistors R1, R2, R3, and capacitors C1 and C2 are used as biasing and temperature stabilization components.

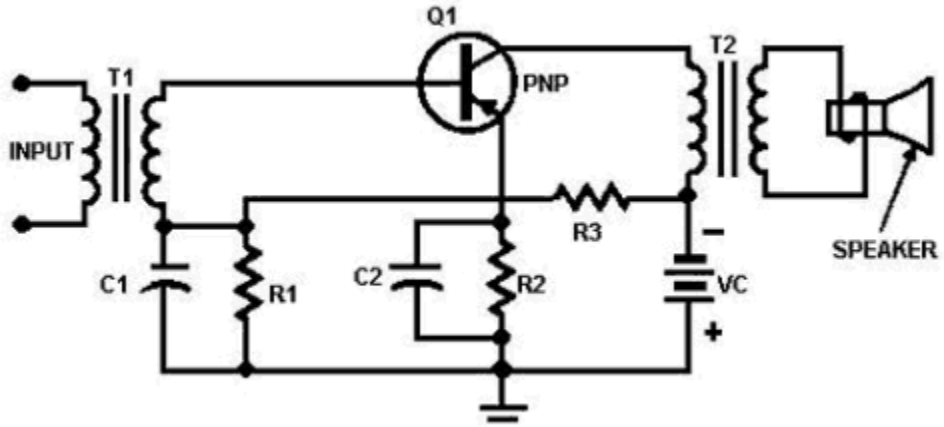


Figure 5-8. Class A, single-ended power amplifier.

c. Class A, Push-Pull Power Amplifier. The class A, push-pull power amplifier (figure 5-9) has two NPN transistors biased for class A operation.

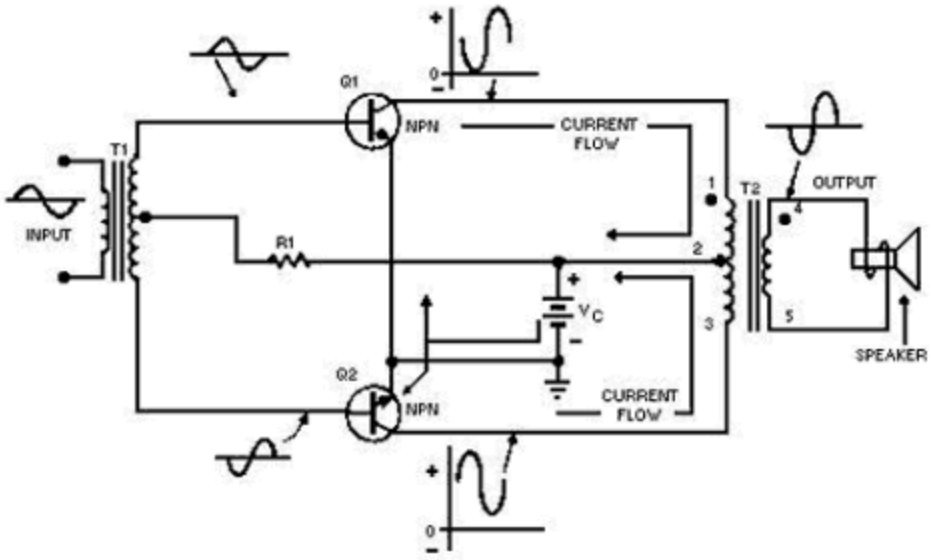


Figure 5-9. Class A, push-pull power amplifier.

(1) Transformer phase splitter circuit T1 applies two 180 degrees out-of-phase signals to the input of the push-pull amplifier. Resistor R1 limits the base bias current and sets the operating point of transistors Q1 and Q2. One-half of the primary of T2 is the collector load for Q1 and the other half is the collector load for Q2. T2 also matches the relatively high output impedances of Q1 and Q2 to the low impedance of the speaker voice coil.

(2) On the positive half of an input cycle, the voltage on the base of Q1 goes more positive, while the voltage at the base of Q2 goes more negative. Since both transistors are NPN's, these voltages on their bases cause current in Q1 to increase and in Q2 to decrease. Current flows from the collector of Q1 and Q2 to the positive side of the battery through the top and bottom halves of the primary winding of T2. Under quiescent (no signal input) operating conditions, these two currents are equal. The value and polarity of the voltage drops these collector currents produce is such that there is no difference of potential between points 1 and 3 of T2. The center tap of T2 is the most positive point because it is connected directly to the positive side of the battery. Therefore, with no signal input, the voltages at points 1 and 3 of T2 are equal and less positive (more negative) than the center tap.

(3) Since the conduction of Q1 increases on the positive half of the input signal, the voltage at point 1 of T2 (same as collector of Q1) swings less positive (swings in the negative direction). At this time Q2 conducts less, causing the signal at the collector of Q2 to swing in the positive direction. Since point 1 of T2 is becoming more negative and point 3 of T2 is becoming more positive, a difference of potential exists across the primary of T2. Effectively the tip of the primary will be more negative than the bottom. By transformer action, this potential difference is coupled to the secondary of T2, and is applied to the speaker voice coil. On the negative alternation of the input signal, the reverse action occurs. The polarity of the voltage developed across the primary of T2 is reversed.

(4) The power output from this class A, push-pull amplifier is more than twice that of a single-ended, class A amplifier. The class A, push-

pull power amplifier finds its greatest application when minimum distortion is the primary consideration and high power output and efficiency is not important.

d. Class B, Push-Pull, Zero Bias Power Amplifier. Figure 5-10 shows a simplified circuit of a class B, push-pull amplifier, The emitter-to-base junctions are zero biased. Each transistor conducts on alternate half cycles of the input signal and their output signals are combined in the secondary of T2. This amplifier gives maximum efficiency but it does produce distortion.

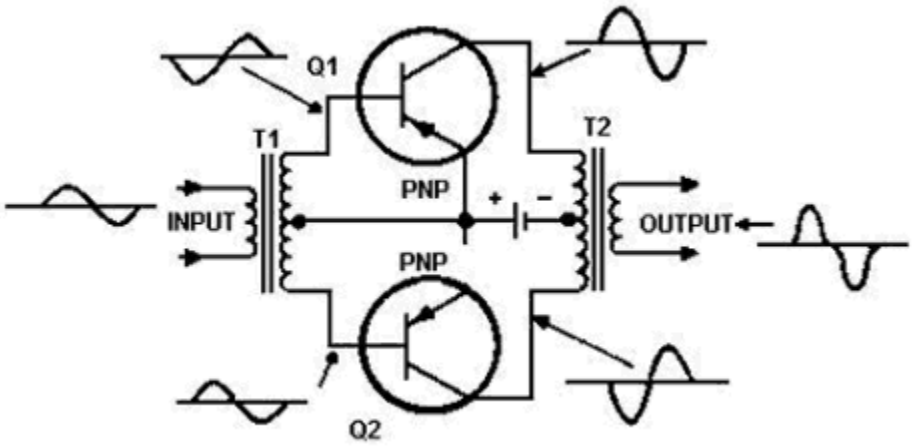


Figure 5-10. Class B, push-pull amplifier with zero input bias.

(1) A representation of the output current waveform for a given signal input is shown in figure 5-11. Assume that the two transistors have identical characteristics. The characteristic curve for one transistor is shown in A of the figure. B of the figure shows the overall characteristic for the push-pull circuit by placing the two individual curves back-to-back. Note that the zero line of each curve is lined up vertically to reflect the zero bias current point. C of the figure shows the input signal projected on the characteristic curve. Corresponding points are projected to form the output collector waveform.

(2) Note that severe distortion occurs, where the signal passes through the zero point. This is called crossover distortion and it becomes more severe with low signal input currents. Crossover distortion can be eliminated by using a small amount of forward bias on both of the transistors.

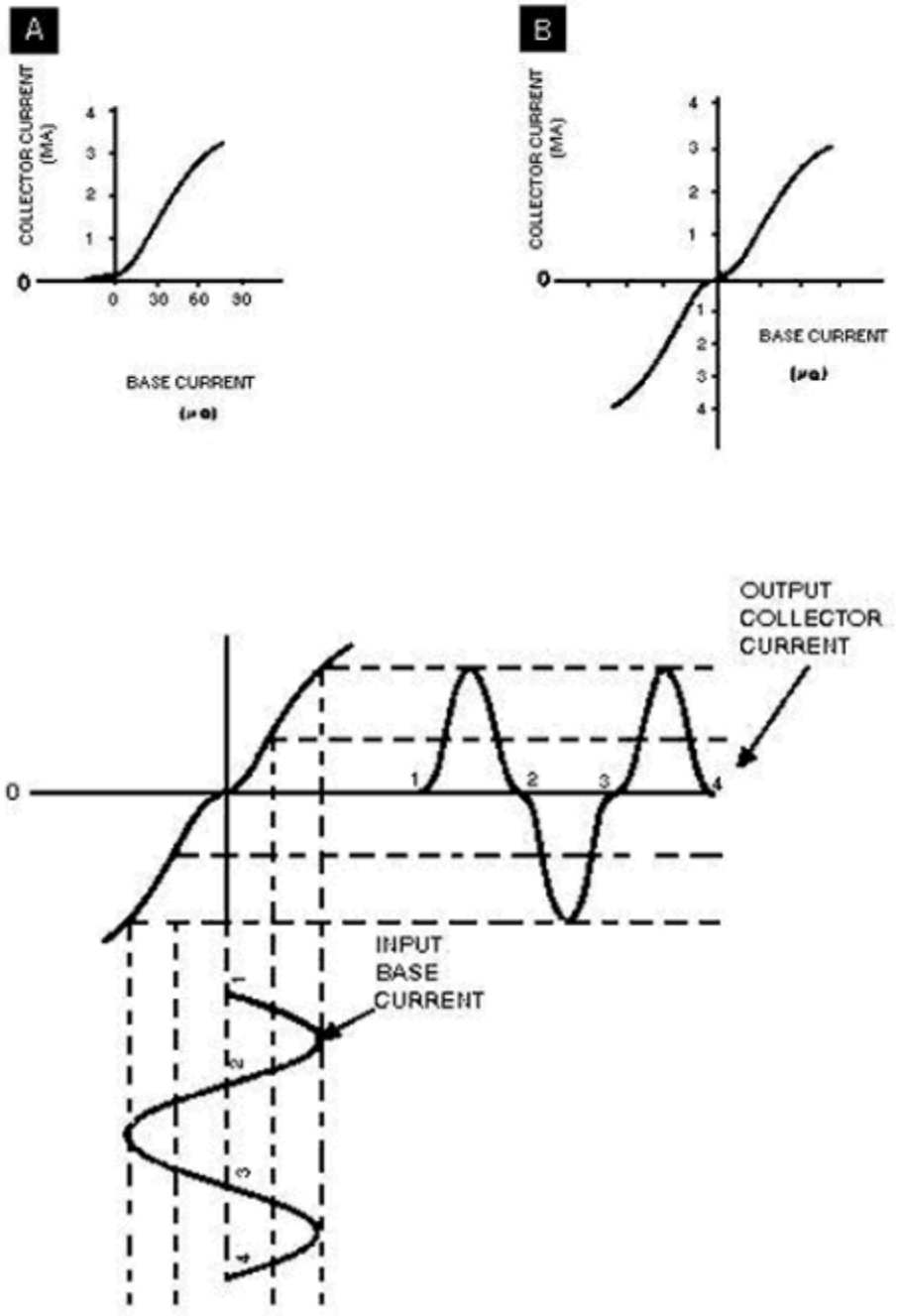


Figure 5-11. Characteristic curves of class B, push-pull amplifier with zero bias, showing input and output current waveforms.

e. Class B, Push-Pull Low Bias Amplifier.

(1) Figure 5-12 shows a small amount of forward bias applied to the base-to-emitter junctions of transistors Q1 and Q2. In the circuit,

resistors R1 and R2 are a voltage divider for the bias battery (the arrow shows direction of current). The voltage developed across R1 provides the forward bias for both transistors. Forward biasing the transistors eliminates crossover distortion.

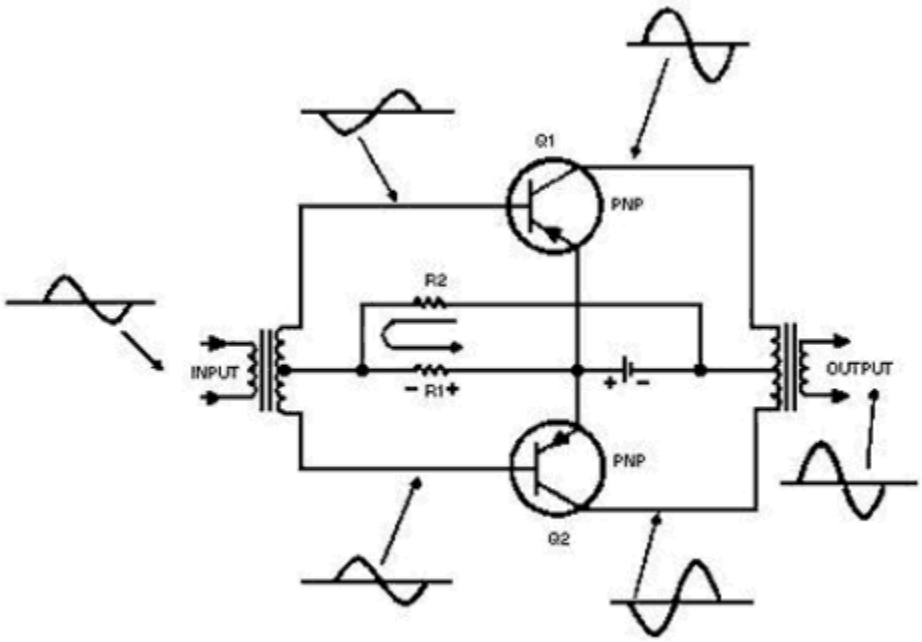


Figure 5-12. Class B push-pull amplifier with small bias voltage.

(2) The characteristic curve of the amplifier (figure 5-13) shows that the crossover distortion is eliminated. Note that the characteristic curve is linear at the zero base current region. Points on the input base current curve are projected on the curve. Corresponding points are then projected to form the output collector current waveform. The result shows that crossover distortion does not occur when a small forward bias is applied.

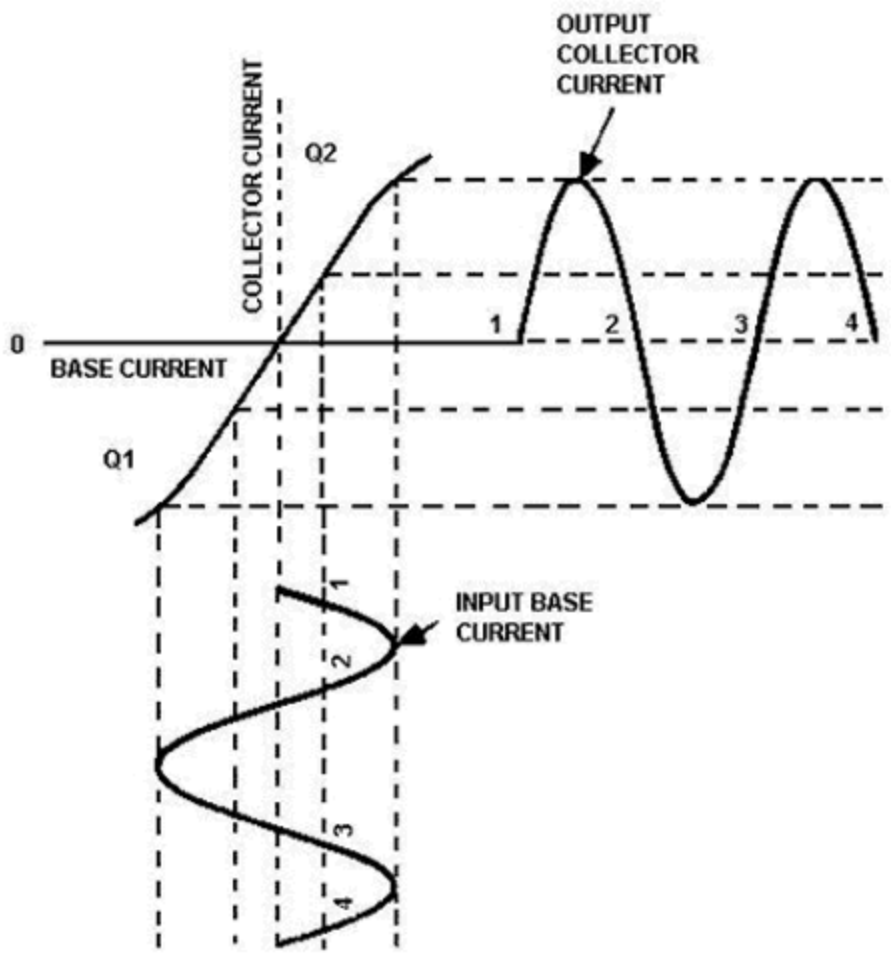


Figure 5-13. Characteristic curves of class B, push-pull amplifier with small forward bias, showing output current waveforms.

f. Complementary Symmetry, Class B. Junction transistors are available as NPN and PNP types. The direction of electron flow of one type is opposite to that of the other type. If the two types are connected as shown in figure 5-14, the circuit is referred to as a complementary symmetry circuit. The name is derived from the fact that the two different transistor types can be combined to operate as one stage. The complementary symmetry circuit provides all the advantages of conventional push-pull amplifiers without the need for a phase-inverter driver stage, or for a center-tapped input transformer.

(1) A positive input signal is required to forward bias Q2 and make it conduct. On the other hand, a negative input signal is required to forward bias Q1 to make it conduct. Thus, when one transistor conducts the other does not, because the input signal that forward biases one transistor reverse biases the other.

(2) With no input signal and class B operation (zero emitter-to-base), neither transistor conducts and no current flows through the speaker coil.

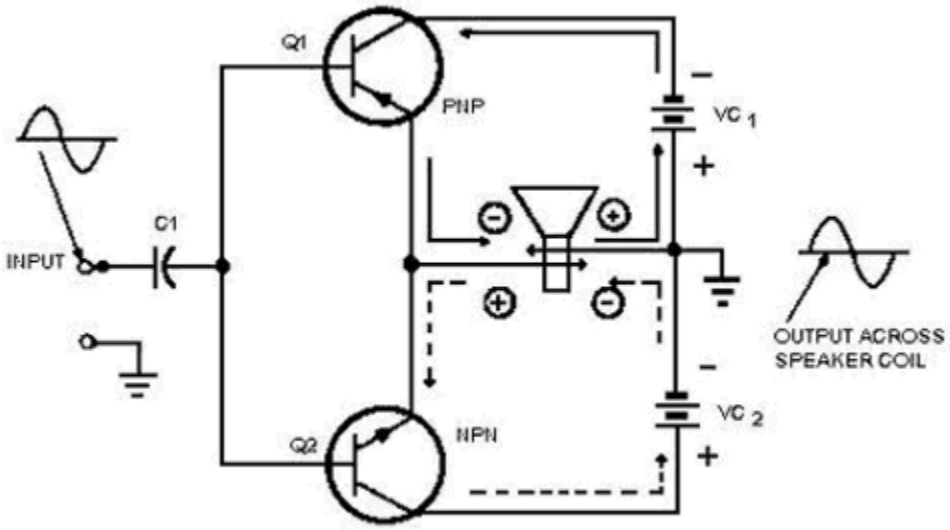


Figure 5-14. Class B, complementary symmetry.

(a) When the input signal swings positive, Q2 conducts. The dashed line indicates current flow at this time. A voltage is developed across the speaker coil with polarity as indicated.

(b) When the input signal swings negative, Q1 conducts. Current flow now changes to the top circuit and is indicated by the solid lines. Notice that the direction of current through the speaker coil has reversed and the polarity across the coil changes.

(c) A sine wave input to the circuit produces a sine wave output across the speaker coil. Thus, the desired reproduction of the input signal is received.

g. Complementary Symmetry, Class A. Figure 5-15 shows a complementary symmetry circuit biased for class A operation: current flows through the circuit at all times. Assume that all components are matched. Resistors R1 and R2 forward bias both Q1 and Q2. The input signal is applied to Q1 and Q2 through capacitors C1 and C2, respectively.

(1) During the no-input signal condition, both Q1 and Q2 conduct equally. Two equal currents flow through the speaker coil but in the opposite direction. The net current in the speaker coil is zero.

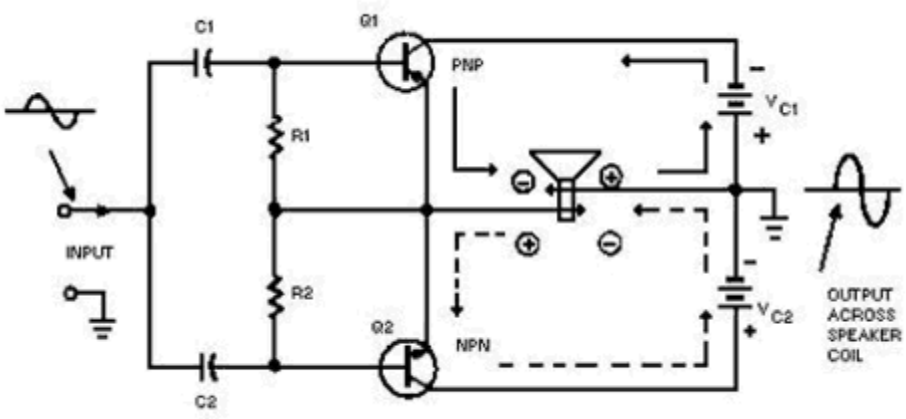


Figure 5-15. Class A, complementary symmetry.

(2) When the positive half of the input cycle is applied to the base of Q1 and Q2, Q1 conducts less (PNP) and Q2 conducts more (NPN). There are still two currents flowing through the speaker coil in opposite directions, but the greater current flows through the circuit of Q2 (dotted line). The two currents oppose each other and the net current is the difference between the two; the voltage developed across the coil has the polarity indicated in the bottom circuit.

(3) When the input signal swings negative, Q1 conducts more than Q2. Therefore, the current through the top circuit is greater than the current through the bottom circuit. The net current develops a voltage across the speaker coil with polarity as indicated in the top circuit. Thus, for each complete input cycle there is a corresponding signal developed across the speaker coil.

5. WIDEBAND AMPLIFIERS.

a. General.

(1) A very important factor in certain applications of an amplifying device is its ability to amplify nonsinusoidal or pulse-shaped signals. Nonsinusoidal signals, such as sawtooth, rectangular, and square waveforms consist of a fundamental frequency and a large number of harmonics or multiples of the fundamental. To produce a pulse-shaped output signal that is an exact reproduction of the input signal, the amplifier must amplify all of the harmonics with uniform gain. This type of amplifier is referred to as a wideband amplifier, a video amplifier, or a pulse amplifier.

(2) The results of narrow-band and wideband amplification of a nonsinusoidal input signal are shown in figure 5-16. The narrow-band amplifier in A does not amplify all of the harmonics and produces a distorted output. The wideband amplifier in B amplifies all of the harmonics; its output is an exact reproduction of the input waveform.

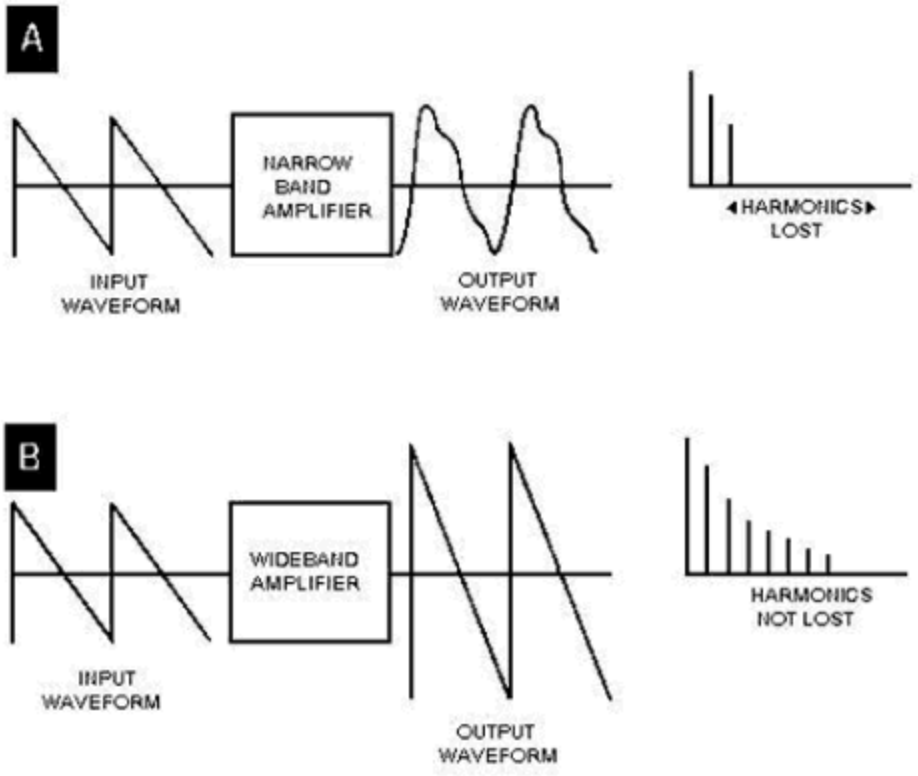
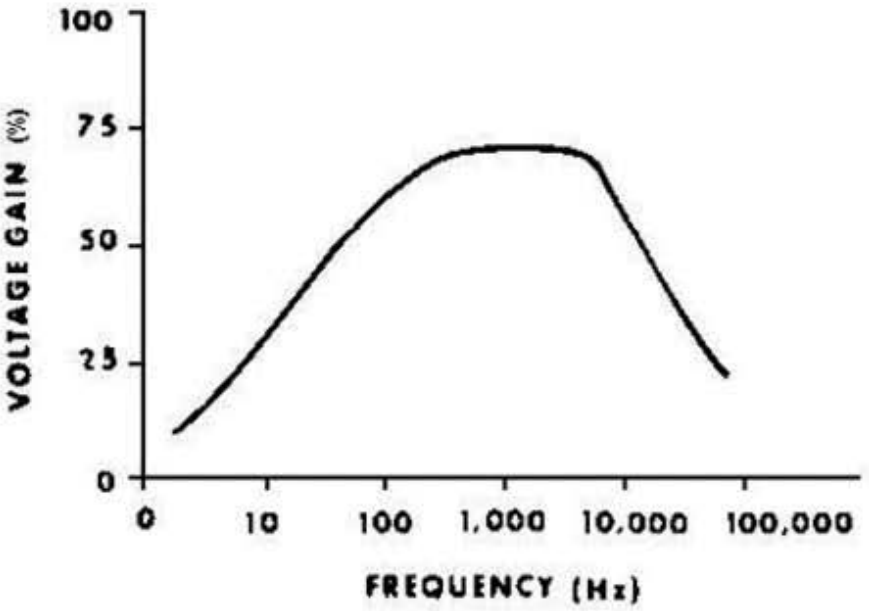


Figure 5-16. Distortion and reproduction of sawtooth waveform by narrow-band and wide-band amplifiers.

b. Wideband Amplifier Coupling Circuits. Resistance-capacitance (RC) coupling is the preferred method of coupling wideband amplifiers. Figure 5-17 shows the frequency response curves of transformer and RC coupling. The frequency response curve in A of the figure is for a transformer coupled amplifier. Its response is not uniform over a wide range of input frequencies; its voltage gain varies as the applied frequency changes. B shows that when RC coupling is used in the same amplifier, its response curve is flatter over a much wider range of input frequencies. However, using special winding techniques, the frequency response curve for transformers can be made as flat as desired. Transformers can then be used in the input and output stages of a wideband amplifier circuit.

A **TRANSFORMER COUPLING**



B **RC COUPLING**

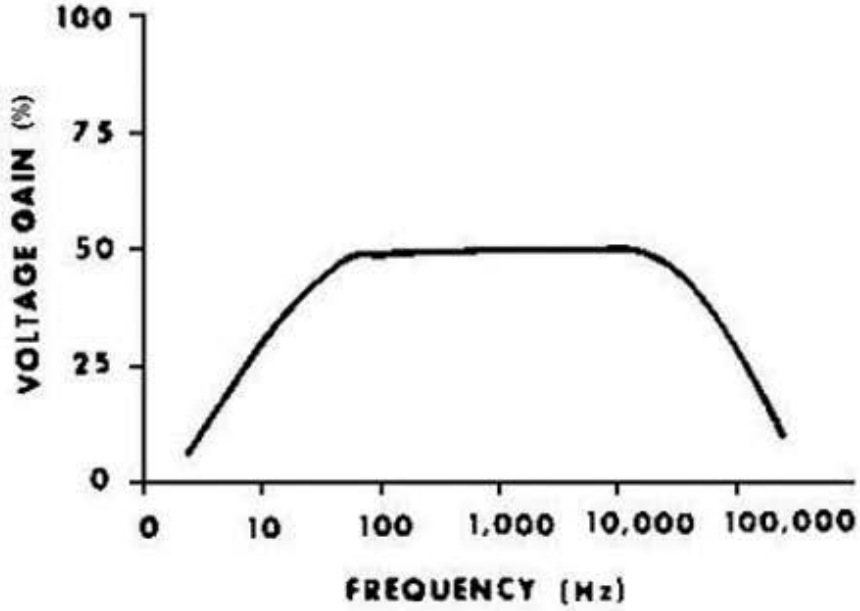


Figure 5-17. Frequency response curves for transformer or RC coupling.

c. High Frequency Compensation. In any RC coupled wide-band amplifier it is necessary to compensate for its high frequency (HF) limitations and its effect on low frequencies.

(1) HF limitations. The HF response of a wideband amplifier is limited by the stray shunt capacitance of its input and output impedances. In figure 5-18, the capacitive effects are shown by the dashed lines labeled Co for the output impedance and Ci for the input impedance. Since the reactances of Co and Ci decrease as the frequency increases, the overall gain falls off at the higher frequencies.

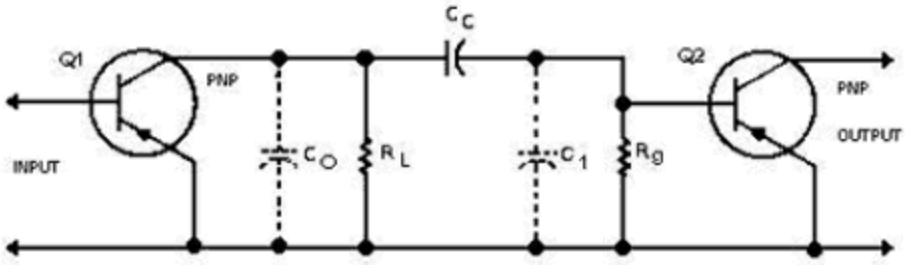


Figure 5-18. RC-coupled amplifier showing capacitive effect on high frequencies.

(2) HF shunt compensation. To compensate for the shunting effect of Co and Ci, inductor L1 is added in series with load resistor RL (A, figure 5-19). Capacitor Cc can be considered a short circuit at high frequencies. Inductor L1 and capacitors Co and Ci form a parallel resonant circuit with a very broad HF response. This compensation is also called shunt peaking.

(a) The resonant peak of the parallel resonant circuit maintains a practically uniform gain in the high frequency range.

(b) When frequency increases, the decrease in the total capacitive reactance of Co plus Ci is compensated for by the increase in the inductive reactance of L1. Thus the gain at higher frequencies remains relatively high and constant.

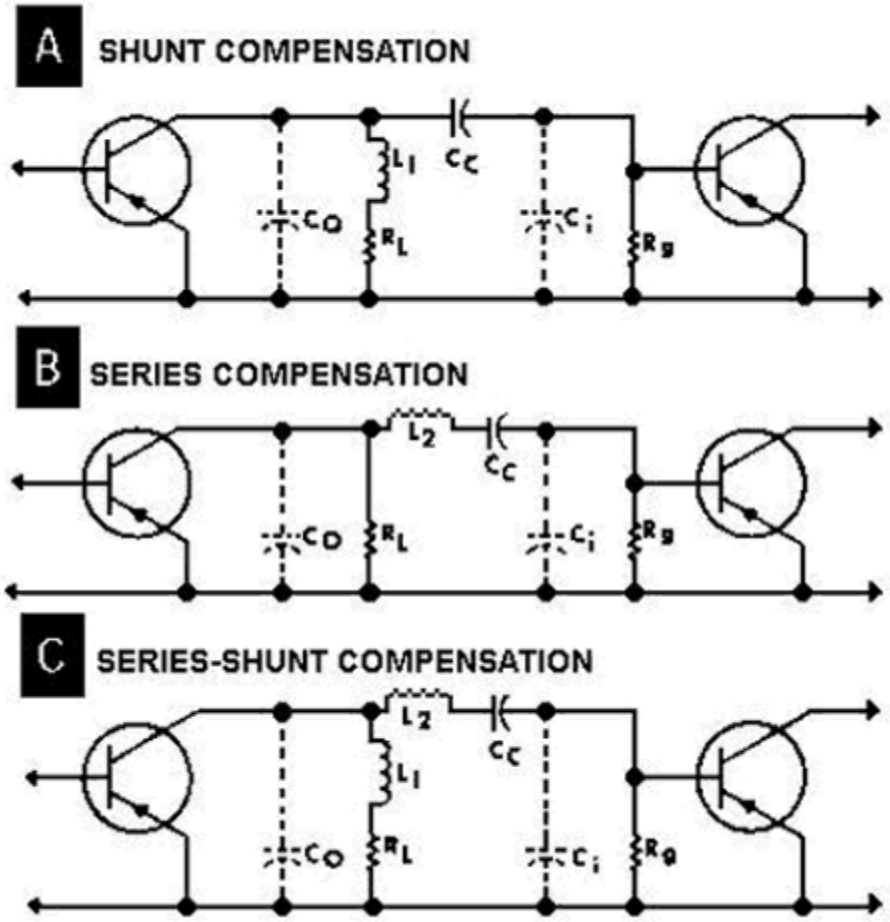


Figure 5-19. Wideband amplifier, high frequency compensating coupling.

(3) HF series compensation. In the series compensation (also known as series peaking) circuit, inductor L2 is added in series with capacitor Cc (B, figure 5-19). Considering Cc as a short circuit at high frequencies, L2 and Ci form a series resonant circuit. As very high frequencies are approached, L2 and Ci approach resonance. When the voltage across RL begins to decrease, because of the decrease in the capacitive reactance of Co, current through Ci will increase. The increase occurs because L2-Ci form a series resonant circuit with high current at resonance. Thus as the frequency increases, the attempted decrease in voltage across RL is compensated for by the increased current flow from the resonant circuit of L2-Ci.

(a) The frequency response curve is approximately the same as for the shunt peaking circuit.

(b) The gain at higher frequencies of the series peaking circuit is about 50 percent greater than that of the shunt peaking circuit.

(4) HF series-shunt compensation. By adding L1 and L2 to the basic circuit the combined effect of series and shunt compensation (C, figure 5-19), is received. This type of coupling is also called combination peaking.

The frequency response is about the same as that of either the series peaking, or shunt peaking coupling circuits. The gain at higher frequencies is approximately 80 percent greater than that of the series peaking coupling circuit.

d. Low Frequency Compensation. A wideband amplifier must have good low frequency (LF) response to reproduce square waves of long duration.

(1) LF limitations. The fundamental and low frequency harmonics of a square wave signal have the greatest amplitude. For example, the third harmonic is one-third the amplitude of the fundamental and much higher in amplitude than higher frequency harmonics. Since the fundamental and low frequency harmonics have the greatest amplitude, any small variation in the phase of the lower frequencies is extremely noticeable. The effect on the higher frequency harmonics is negligible since their amplitudes are progressively decreased.

(2) LF compensation. On the low frequency end of the frequency response range, the input and output capacitance of the transistor have no effect on the frequency response. The low frequency response is limited by the RC coupling circuit of capacitor Cc and resistor Rg (figure 5-20). The time constant of Rg and Cc must be long in comparison to the lowest frequency to be amplified to prevent the low frequency response from falling off.

(a) The loss of gain at low frequencies is minimized by adding a compensating filter in series with load resistor RL. The filter consists of resistor RF and capacitor CF. For high frequencies, CF is practically a short circuit and the collector load impedance consists only of RL. As the frequency decreases, the reactance of CF increases. At very low frequencies, CF is practically an open circuit, and the collector load impedance consists of RL and RF. Thus, the filter increases the collector load impedance at low frequencies.

(b) This combination extends the frequency response curve over a much lower range of frequencies. The gain becomes more uniform over the low frequency range.

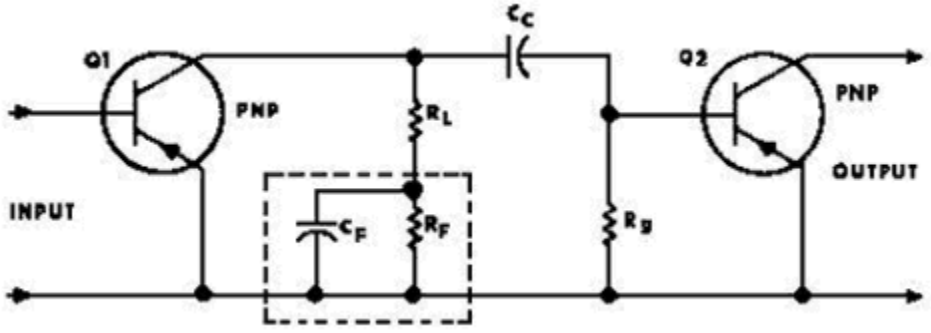


Figure 5-20. Wideband amplifier, low frequency compensating coupling.

MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS

EXERCISES FOR LESSON 5

1. Collector current flows during 360 degrees of the input cycle for class A amplifiers, approximately 220 degrees to 320 degrees for class AB, 180 degrees for class B, and 90 degrees for class C. Which of these four classes is used in a transmitter that provides a high-power output?

   A. A
   B. B
   C. C
   D. AB

2. What type of coupling network is used in the circuit illustrated in figure 5-2?

   A. Direct
   B. Impedance
   C. Transformer
   D. Resistance-capacitance

3. Which circuit shown in figure 5-1 gives an ideal transistor current stability factor if a swamping resistor is used in the emitter lead?

   A. A
   B. B
   C. C
   D. D

4. The theoretical maximum power efficiency of a coupling circuit between amplifier stages is 50 percent. The amplifier circuit shown in figure 5-1 that provides the highest efficiency is the one shown in part

   A. A.
   B. B.
   C. C.
   D. D.

5. What class of amplifier must operate push-pull in order to avoid severe signal distortion?

   A. A
   B. AB
   C. B
   D. C

6. Only one of the coupling networks is used with amplifiers where dc and very low frequencies must be amplified. This coupling network is called

   A. resistance-capacitance (RC) coupling.
   B. transformer coupling.
   C. impedance coupling.
   D. direct coupling.

7. Maximum gain is provided by transistor Q2 in figure 5-2 when the

   A. output of Q1 is at maximum amplitude.
   B. movable arm of resistor R2 is at its lowest position.
   C. movable arm of resistor R2 is at its uppermost position.
   D. capacitive reactance of capacitor C1 exceeds the resistance of R2.

8. Alterations must be made to the circuit shown in figure 5-4 so that the circuit will produce the desired outputs. These alterations involve adding another resistor in series with

   A. R1 and decreasing the value of R2.
   B. R3 and increasing the value of R1.
   C. C1 and decreasing the value of R1.
   D. C2 and increasing the value of R2.

9. In the two-stage phase inverter shown in figure 5-6, base bias is developed by resistors R1 and R5, and the two output signals are developed across resistors

   A. R2 and R7.
   B. R3 and R6.
   C. R4 and R6.
   D. R6 and R7.

10. In the inverter shown in figure 5-7, the directly coupled input to Q2 is developed across

    A. R2.
    B. R3.
    C. R5.
    D. C1.

11. Power amplifier stages are physically larger and mounted differently than voltage amplifier stages. The reason for these differences is that

    A. lower load impedances arc used.
    B. greater heat must be dissipated.
    C. the stages are only 50 percent efficient.
    D. each stage requires twice as many components.

12. Under what circumstances will you find a class A push-pull amplifier?

    A. Where the primary consideration is minimum distortion, and high-power output and efficiency are not important
    B. Where the primary consideration is high-power output, and distortion and efficiency are not important
    C. Where the primary consideration is maximum efficiency, and high power output and distortion are not important
    D. Where the primary consideration is high power output and maximum efficiency, and distortion is not important

13. During what portion of the input signal to T1 (figure 5-9) will you measure a 0-volt difference of potential between terminals 1 and 3 of T2?

    A. At 0 volt
    B. At maximum (+)
    C. At minimum (-)
    D. At one-half of the positive value

14. Crossover distortion occurs in a class B, zero bias, push-pull amplifier circuit because the

    A. input signal is most distorted when it is at zero.
    B. transistors are overdriven at the crossover points.
    C. transistors have different transfer characteristics.
    D. circuit has nonlinear response curve for low input base currents.

15. How can the circuit shown in figure 5-10 be modified to eliminate the crossover distortion of the output signal?

    A. Add a forward-biasing circuit for Q1 and Q2
    B. Add a reverse-biasing circuit for Q1 and Q2
    C. Add a swamping resistor in the emitter circuits of Q1 and Q2
    D. Add a compensating filter in series with the collector load of Q1 and Q2

16. The operation of the class B complementary symmetry circuit shown in figure 5-14 is similar to that of the push-pull circuit in figure 5-10 in that only one transistor passes current at a given time. In figure 5-14 the base-emitter junctions of Q1 and Q2 are forward biased by

    A. input positive half cycle only.
    B. input negative half cycle only.
    C. the input positive and negative half cycle respectively.
    D. VC1 and VC2.

17. Complementary symmetry circuits may be used to obtain all of the advantages resulting from push-pull operation in audio power amplifiers. An additional advantage derived from using complementary circuits in place of conventional push-pull amplifiers is that these circuits

    A. can use either RC or transformer coupling.
    B. can be operated either class A or class B.
    C. use discharge diodes to eliminate reverse bias.
    D. do not require a phase-splitting circuit to divide a single audio input signal.

18. What circuit factors can cause poor high-frequency response in a two-stage RC coupled amplifier?

A. Input and output resistances
B. Input and output impedances
C. Input impedance and time constant of RC coupling network
D. Output impedance and time constant of RC coupling network

19. What is the percentage gain of a combination-peaking over series-peaking high frequency compensation circuits?

A. 30
B. 50
C. 80
D. 100

20. Wideband amplifiers must have low- and high-frequency response to reproduce various nonsinusoidal waveforms. What best describes the composition and placement of a low-frequency compensation circuit?

A. Series resistance-inductance (RL) circuit in series with the coupling network
B. Series RC circuit in parallel with the base input resistor
C. Parallel RC circuit in series with the collector load resistor
D. Parallel RL circuit in parallel with the interstage coupling capacitor

LESSON 6. OSCILLATORS AND MULTIVIBRATORS

MMS Subcourse Number 701.....	**Transistors and Semiconductors**
Lesson Objective.....	**To provide the student with a general knowledge of LC resonant feedback, RC feedback, and free-running nonsinusoidal oscillators.**
Credit Hours.....	**Four**

TEXT

1. LC RESONANT FEEDBACK OSCILLATORS.

a. General.

(1) The rapid alternating motion (oscillation) of electrons in a conductor results in radiation of electromagnetic waves. The term oscillate is defined as "to swing or move back and forth." An oscillator is defined as "a device which oscillates or produces oscillations." The purpose of a transistor oscillator is to produce the rapid back and forth, or alternating, motions of electrons: it produces alternating current from a direct current supply.

(2) All transistor oscillator circuits have the same basic requirements. An oscillator must use an amplifier in which the output power is greater than the input power to overcome circuit losses. There must be a frequency controlling device such as a tank circuit (coils and capacitors), a crystal controlled network, or an RC feedback network. Also, the circuit must be arranged so that a portion of the output signal feeds an in-phase signal back to the input to sustain oscillations (figure 6-1). The feedback is called regenerative or positive feedback.

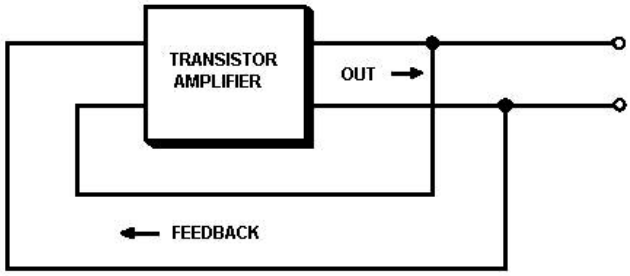


Figure 6-1. Transistor oscillator showing application of feedback.

(3) There are many types of transistor oscillators. The basic ones are the Armstrong, Hartley, Colpitts and crystal controlled oscillators. The oscillator can be of the NPN or PNP type, the only difference is the reversal of the battery potentials. The choice of a particular configuration (common base, common emitter, or common collector) is determined by the oscillator requirements and the advantage of one amplifier configuration over another.

b. Basic Transistor Oscillator Circuits.

(1) Figure 6-2 shows different component arrangements for basic oscillator circuits with PNP transistors. Each circuit provides amplification, regenerative feedback, and inductance-capacitance tuning. Bias and stabilization components are not shown, but the dc voltage polarities for normal operation are included. NPN transistors may be substituted in any of these circuits, provided that the dc polarities are reversed.

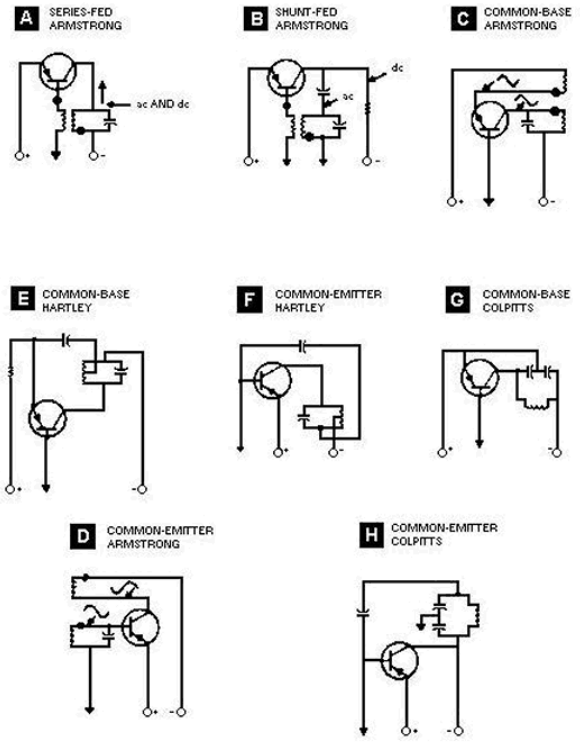


Figure 6-2. Basic transistor oscillator circuits.

(2) The circuits in A and B, figure 6-2, are similar. In both cases the feedback signal is coupled from the collector to the base through a transformer. Circuit B is a shunt-fed version of circuit A. Shunt-fed means that the dc and ac components are separated and only ac flows through the collector tank circuit. Since the feedback path is from collector to base, the necessary phase inversion of the feedback signal is accomplished by the transformer which provides a 180 degree phase shift. In circuit C of the figure, regenerative feedback with zero phase shift is obtained in the tuned collector-to-emitter circuit by proper connection of the transformer. In circuit D of the figure, a 180 degree phase shift is obtained from the transformer: the signal in the untuned collector winding is coupled and inverted in phase to the tuned-base winding.

(3) The circuits E and F, figure 6-2, use split inductances to provide the necessary feedback. In both circuits the collector circuit is tuned. Each half of the coil provides the necessary feedback of the proper phase. In circuit E, the feedback signal is coupled from the collector to the emitter with no phase shift. In circuit F, the feedback signal is coupled from the collector to the base with a 180 degree phase shift. Circuits G and H of the figure are similar to those in E and F except that split capacitor circuits are used for feedback instead of split coils.

c. Armstrong Oscillator (Tickler Coil), Tuned Base.

(1) The components within the dashed lines on figure 6-3 are the transistor amplifier circuit. Resistors RB, RC, and RF provide the necessary bias conditions, and RE is the emitter swamping resistor, for stabilization. The shunt-feed arrangement of the collector prevents dc through the ticklet coil L1. The feedback is through the mutual inductance between coils L1 and L2.

(2) The tank circuit consisting of L2 and C1 is the frequency determining device of the oscillator. Variable capacitor C1 permits tuning the tank circuit through a range of frequencies. Capacitor Cc couples the collector sine wave signal to the base of the transistor. Without capacitor Cc, the base bias condition would be determined primarily by the low dc resistance of coil L2. Capacitor CE bypasses the ac signal around the emitter swamping resistor RE, and prevents degeneration.

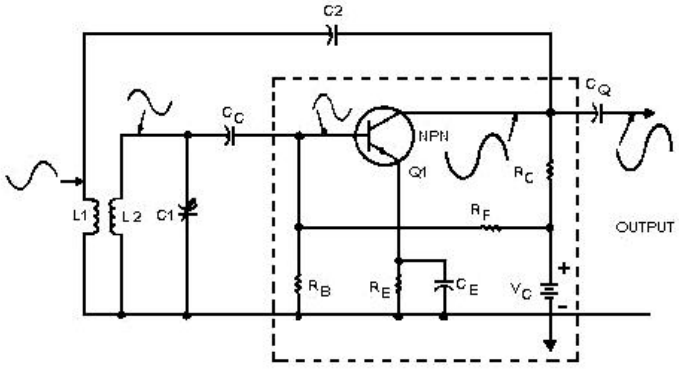


Figure 6-3. Armstrong oscillator, tuned base.

(3) The instant that power is applied, the voltage divider of RF and RB forward biases the transistor into conduction. Current from the emitter to the collector is induced into the tank circuit (L2 and C1) and shocks it into oscillation at a frequency determined by the setting of C1. As the signal from the tank circuit swings positive, the forward bias of the transistor increases and causes it to conduct more. The signal at the collector will swing in the negative direction. There is a 180 degree difference between the base and collector signals. In order to maintain oscillations it is necessary to feed a portion of the collector signal, in phase, back to the tank circuit. This is done by transformer action between coils L1 and L2 through C2. The transformer action provides another 180 degree phase shift (for a total of 360 degrees) resulting in regenerative feedback. If an in-phase portion of the signal is not fed back to the tank circuit, the oscillations would stop after a few cycles (figure 6-4). When the tank circuit reverses its direction (charge and discharge of Cl), the conduction of Q1 is reduced and the collector swings in a positive direction. This positive half cycle in turn, is inverted 180 degrees by transformer action to sustain oscillations of the tank circuit.

(4) If the voltage (dc) developed across RE and CE is equal to the base voltage (dc), the oscillator operates at cutoff (class B). If the emitter voltage is more positive than the base voltage, the oscillator operates below cutoff (class C). If a defective resistor or capacitor in either the voltage divider or the emitter circuit is replaced, it is necessary to use the correct value component or the bias voltages may change the class of operation.

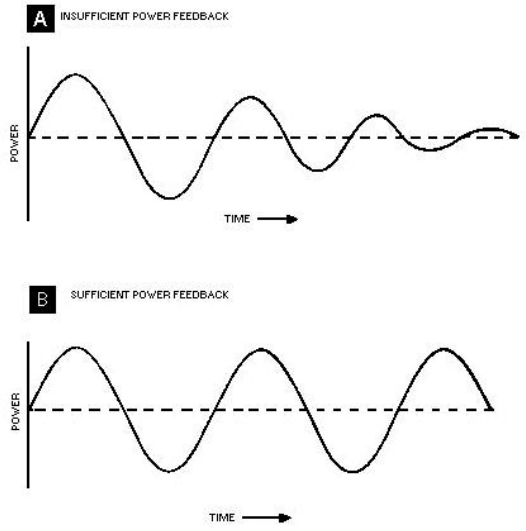


Figure 6-4. Waveforms showing effects of sufficient and insufficient power feedback.

d. Armstrong Oscillator, Tuned Collector.

(1) The tuned collector circuit is very similar to the tuned base circuit. Its major difference is that the frequency determining circuit is in the collector rather than the base circuit. Figure 6-5 shows a series-fed arrangement. A shunt-fed circuit of the tuned collector oscillator is possible with a slight circuit modification.

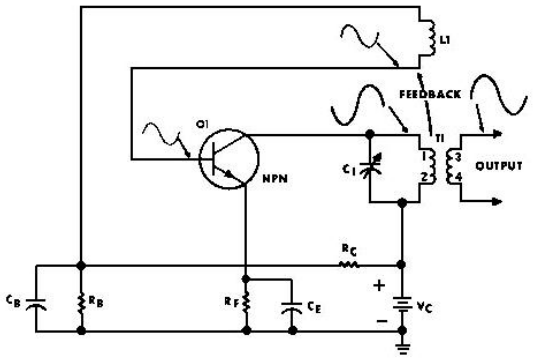


Figure 6-5. Armstrong oscillator, tuned collector.

(2) Resistors RF and RB establish the base bias. RF is the emitter swamping resistor. Capacitors CB and CE bypass ac variations around RB and RF. The tank circuit consists of the primary transformer T1 and variable capacitor C1. Coil L1 is the tickler coil and feeds a portion of the collector signal back to the base in the proper phase to sustain oscillations (regenerative feedback). The secondary of T1 couples the alternating signal output to the next stage. To change the frequency of the oscillator, the capacitance of C1 in the tank circuit is varied.

e. Hartley Oscillator. The Hartley oscillator is an improvement over the Armstrong oscillator. Although its frequency stability is not the best, the Hartley oscillator can generate a wide range of frequencies and is very easy to tune. There are two versions of this oscillator: the series-fed and the shunt-fed. The main difference between the Armstrong and Hartley oscillators is the feedback or tickler coil. In the Hartley oscillator a separate coil is not used. The coil in the tank circuit is a split inductor and a part of it is used for feedback.

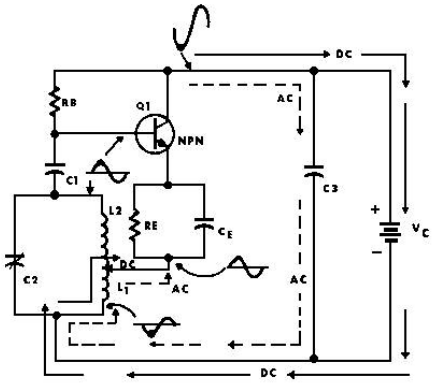


Figure 6-6. Series-fed Hartley oscillator.

(1) Series-fed Hartley oscillator. Figure 6-6 shows one version of a series-fed Hartley oscillator. The tank circuit consists of coils L1, L2, and capacitor C2. The feedback circuit is from the tank circuit to the base of Q1 through C1. Capacitor C3 bypasses the sine wave signal around the battery and swamping resistor RE is used to prevent thermal runaway. Degeneration is prevented by CE in parallel with RE. The amount of bias is determined by the values of RB, the emitter-to-base resistance, the small amount of dc resistance of coil L1 and the resistance of RE. Coupling capacitor C1 is necessary to prevent the low dc resistance of L2 from placing a short across the emitter-to-base junction and resistor RE.

(a) When a voltage is applied to the circuit, current from the battery flows through coil L1, and to the emitter through RE. Current then flows from the emitter to the collector and back to the battery. The surge of current through coil L1 induces a voltage in coil L2 to start oscillations within the tank circuit.

(b) When current first starts to flow through coil L1, the bottom of L1 is negative with respect to the top of L1. The voltage induced into coil L2 makes the top of L2 positive. As the top of L2 becomes positive, the positive potential is coupled to the base of Q1 by capacitor C1. A positive potential on the base results in an increase of the forward bias of Q1 and causes collector current to increase. The increased collector current also increases the emitter current flowing through coil L1. Increased current through L1 results in more energy supplied to the tank circuit, which, in turn, increases the positive potential at the top of the tank and increases the forward bias of Q1. This action continues until the rate of change through coil L1 can no longer increase. The increasing current through coil L1 and the transistor cannot continue indefinitely or the coil and transistor will burn up. The circuit must be designed by proper selection of the transistor and associated parts so that some point is reached when the current can no longer continue to increase. At this point (shown as heavy dot on base wave form), less energy is supplied to the tank circuit through normal tank circuit action. The positive potential at the top of the tank begins to decrease. This causes a decrease in the forward bias which, in turn, causes the collector and emitter currents to decrease. At the instant the potential of the tank circuit decreases to zero, the energy of the tank circuit is contained in the magnetic field of the coil and the oscillator has completed a half cycle of operation.

(c) Next, the magnetic field around L2 collapses, capacitor C2 charges in the opposite direction and the top of L2 starts to become negative. This negative potential is coupled to the base of Q1, opposing its forward bias. Most transistor oscillators are operated class A, therefore the positive and negative signals applied to the base of Q1 will not cause it to go to saturation or to cutoff. When the tank circuit reaches its most maximum negative value, the collector and emitter currents will still be present but at some minimum value. The magnetic field will have collapsed and three-fourths of a cycle will have been completed.

(d) At this point C2 will begin to discharge, decreasing the negative potential at the top of L2 (potential will swing in the positive direction). As the negative potential applied to the base of Q1 decreases, the opposition to the forward bias also decreases. This, in effect, causes the forward bias to begin increasing and there is a resultant increase in emitter current flowing through L1. The increase in current through L1 causes additional energy to be fed to the tank circuit to replace lost energy. If the energy lost in the tank is replaced with an equal or larger amount of energy, oscillations will be sustained. One cycle has now been completed which is repeated over and over again.

(2) Shunt-fed Hartley oscillator. Figure 6-7 shows a version of a shunt-fed Hartley oscillator. The parts in this circuit perform the same basic functions as do their counterparts in the series-fed Hartley oscillator. The chief difference in the shunt-fed circuit is that dc does not flow through the tank circuit (solid arrow lines). This prevents possible injury to anyone who may accidentally touch the tuned circuit coils while tuning the oscillator to a desired operating frequency. The shunt-fed circuit operation is essentially the same as the series-fed Hartley oscillator. When voltage is applied to the circuit, Q1 starts conducting. As the collector current of Q1 increases, the change (increase) is coupled through capacitor C3 to the tank circuit, shocking it into oscillation. C3 also acts as an isolation capacitor to prevent dc from flowing through the feedback coil. The oscillations at the collector (shown as dotted arrows) will be coupled through C3 (feedback) to supply energy lost within the tank.

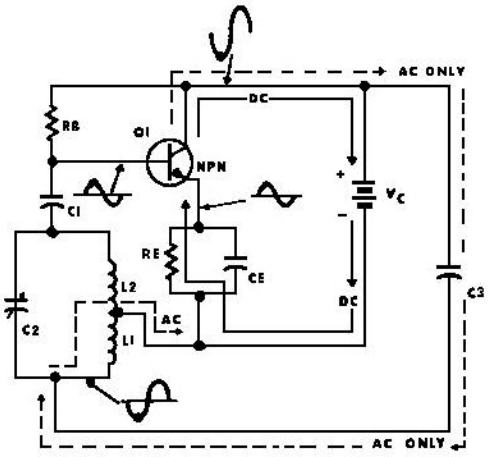


Figure 6-7. Shunt-fed Hartley oscillator.

f. Colpitts Oscillator. Both the Armstrong and Hartley oscillators have a tendency to be unstable in frequency. In comparison, the Colpitts oscillator has fairly good frequency stability, is easy to tune, and can be used for a wide range of frequencies.

(1) The Colpitts oscillator is very similar to the shunt-fed Hartley oscillator, except that two capacitors are used in a tank circuit instead of a tapped coil (figure 6-8). The Hartley oscillator has a tap between two coils, while the Colpitts has a tap between two capacitors. Frequency can be changed in the Colpitts oscillator either by varying the inductance of the coil or by varying the capacitance of the two capacitors in the tank circuit. Notice that no coupling capacitor is used between the tank circuit and the base of Q1. Capacitors C1 and C2 of the tank circuit are in parallel with the input and output inter-element capacitances (capacitance between emitter, base and collector) of the transistor. Thus, the input and output capacitance effect on the tank circuit can be minimized and better frequency stability is attained than with the Armstrong or Hartley oscillators.

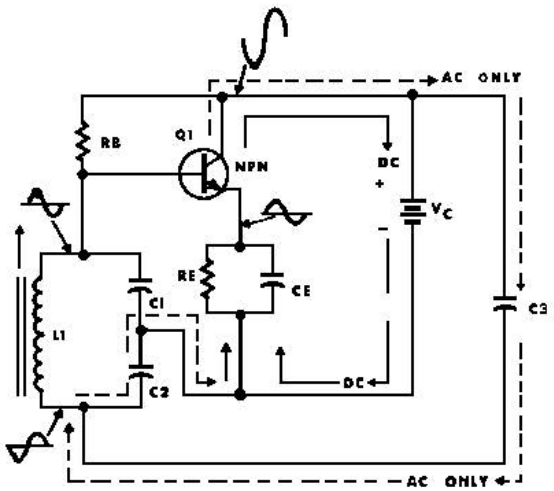


Figure 6-8. Colpitts oscillator.

(2) Figure 6-9 shows a common base Colpitts oscillator using a PNP transistor as the amplifying device. Notice in this version of the Colpitts oscillator that regenerative feedback is obtained from the tank circuit and applied to the emitter. Base bias is provided by resistors RB and RF. Resistor RC is the collector load resistor. Resistor RE develops the input signal and also acts as the emitter swamping resistor. The tuned circuit consists of C1 and C2 in parallel with the 1-2 winding of transformer T1. The voltage developed across C2 is the feedback voltage. Either or both capacitors may be adjusted to control the frequency. In the common base configuration there is no difference between the signal at the collector and the emitter signal. Therefore, the phase of the feedback signal does not have to be changed. When the emitter swings negative, the collector also swings negative and C2 charges negatively at the junction of C1 and C2. This negative charge across C2 is fed back to the emitter.

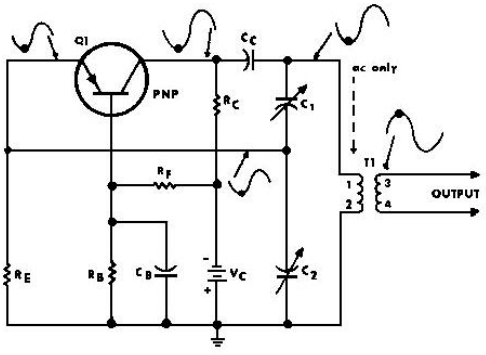


Figure 6-9. Common base Colpitts oscillator.

g. Clapp Oscillator. By modifying the Colpitts oscillator, it is possible to obtain still another oscillator called a Clapp oscillator (figure 6-10). The only difference between the Colpitts oscillator and the Clapp oscillator is the addition of a variable capacitor in series with the inductance of the tank circuit. The added capacitance further improves its frequency stability.

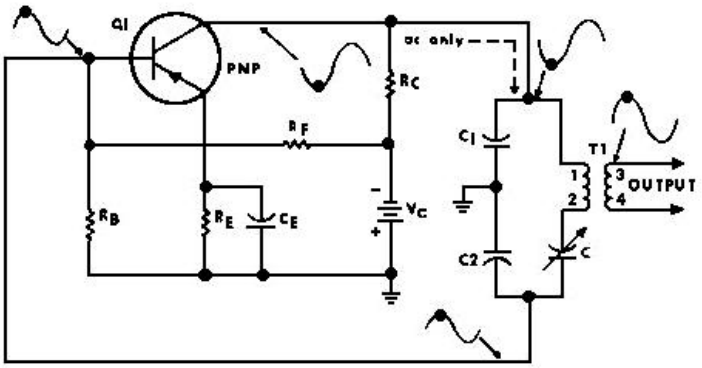


Figure 6-10. Clapp oscillator.

h. Crystal Controlled Oscillator. Certain crystal materials can be used to replace the coil and capacitor in the tank circuit of an oscillator. When a crystal is used, the results are excellent because the oscillator will generate a precise, stable frequency. Quartz crystals are often used in oscillators.

(1) If a mechanical force is applied to a crystal and causes it to vibrate, it generates an ac voltage. This action works the other way around also. If an ac voltage is applied to a crystal, it will cause it to vibrate. The relationship between the mechanical and electrical effects is known as the pressure-electric effect or, more commonly, the Piezo-electric effect.

(2) When a crystal is used in an oscillator circuit, it is mounted between two metal plates in a special holder. Voltage is applied to the metal plates and causes the crystal to vibrate. Once it starts vibrating, it begins to generate an ac voltage that is the output frequency of the oscillator. To keep the crystal vibrating (or to sustain oscillations) a small amount of voltage is fed back from the output of the amplifier (regenerative feedback).

(3) Based on what has been stated so far, the crystal must have a resonant frequency. It's a natural resonant frequency and depends on how the crystal is cut: the thickness of the crystal is its important feature. Different size crystals vibrate (resonate) at different frequencies. Thus to change the frequency of a crystal controlled oscillator, the crystal must be changed. The thinner the crystal, the higher will be its natural resonant frequency. Since the output ac voltage depends on the resonant frequency of the crystal, the thinner the crystal, the higher will be the output ac voltage frequency of the oscillator. One fact to remember: at the specific frequency (of vibration) when the crystal. produces its highest amplitude of output voltage, it is the equivalent of a resonant circuit.

(4) It may seem to be a disadvantage that a crystal will generate only one frequency. However, crystals can be switched into or out of an oscillator very easily, which increases their versatility. In addition, there is a process called frequency synthesis in which many different frequencies can be obtained from the very stable output of a single, crystal controlled oscillator.

i. How A Crystal Works As A Tuned Circuit. A quartz crystal and its equivalent circuit are shown in figure 6-11. Capacitor CS, inductor L, and resistor R represent the electrical equivalent of the quartz crystal (B, figure 6-11). Capacitor CP represents the capacitance between the crystal electrodes (A, figure 6-11). Depending upon the circuit characteristics, the crystal can act as a capacitor, an inductor, a series tuned circuit, or a parallel tuned circuit.

(1) At some frequency the reactances of equivalent capacitor CS and inductor L will be equal and the crystal will act as a series tuned circuit. A series tuned circuit has a minimum impedance at resonance (figure 6-12). Above resonance the series tuned circuit acts inductively and below resonance it acts capacitively . In other words the crystal unit has its lowest impedance at the series resonant frequency and the impedance increases as the frequency is lowered because the unit acts as a capacitor. The impedance of the crystal unit will also increase as the frequency is raised above the series resonant point, because the unit reacts as an inductor. Therefore, the crystal unit reacts as a series tuned circuit.

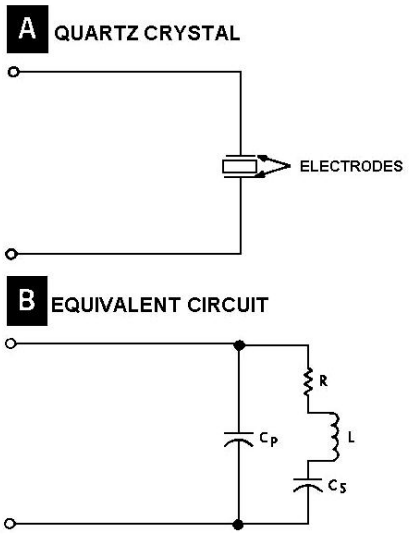


Figure 6-11. Quartz crystal and its equivalent circuit.

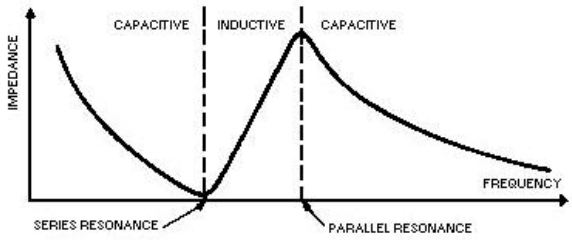


Figure 6-12. The frequency response of a crystal unit.

(2) Since the series tuned circuit acts as an inductor above the series resonant point, the crystal unit becomes equivalent to an inductor and is in parallel with equivalent capacitor Cp (B, figure 6-11). Therefore, at some frequency above the series resonant point, the crystal unit will act as a parallel tuned circuit. A parallel tuned circuit has a maximum impedance at the parallel resonant frequency, and acts inductively below parallel resonance and capacitively above parallel resonance (figure 6-12). Therefore, at some frequency the crystal unit will act as a parallel tuned circuit.

j. Crystal Controlled Armstrong Oscillator. This circuit (figure 6-13) uses the series tuned mode of operation. It works much the same as the Hartley oscillator except that frequency stability is improved by the crystal (in the feedback path). To operate at different frequencies, crystals may be changed.

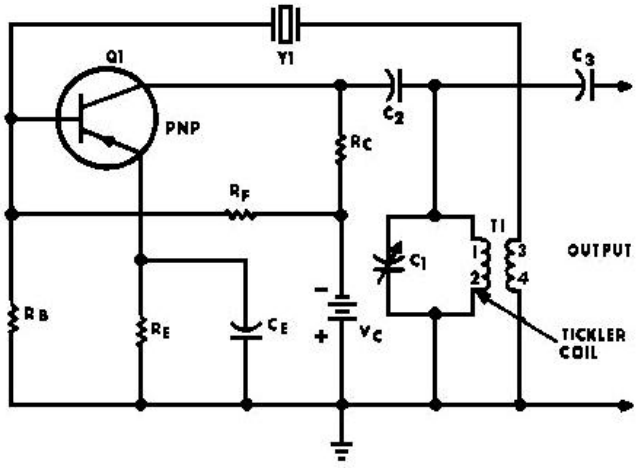


Figure 6-13. Crystal controlled Armstrong oscillator.

(1) Variable capacitor C1 makes the circuit tunable to the selected crystal frequency. C1 is capable of tuning to a wide band of selected crystal frequencies. Regenerative feedback from collector to base is through the mutual inductance between transformer windings 1-2 and 3-4. This provides the necessary 180 degree phase shift for the feedback signal. Resistors RB, RF, and RC, provide the base and collector bias voltages. Capacitor CE bypasses ac variations around emitter swamping resistor RE.

(2) At frequencies above and below the series resonant frequency of the selected crystal, its impedance increases and reduces the amount of feedback signal. This, in turn, prevents oscillation at frequencies other than its series resonant frequency.

k. Crystal Controlled Pierce Oscillator. This oscillator uses a crystal unit as a parallel resonant circuit. The Pierce oscillator is a modified Colpitts oscillator; they operate in the same way except that the crystal unit replaces the parallel resonant circuit of the Colpitts.

(1) Figure 6-14 shows the common base configuration of the Pierce oscillator. Feedback is supplied from the collector to the emitter through capacitor C1. Resistors RB, RC, and RF provide the proper bias conditions for the circuit and resistor RE is the emitter swamping resistor. Capacitors C1 and CE form a voltage divider connected across the output. Since no phase shift occurs in the common base circuit, capacitor C1 feeds back a portion of the output signal to the emitter without a shift in phase. The oscillating frequency is determined not only by the crystal but also by the parallel capacitance caused by capacitors C1 and CE. The parallel capacitance affects the oscillator frequency; any change in capacitance of either C1 or CE changes the frequency of the oscillator.

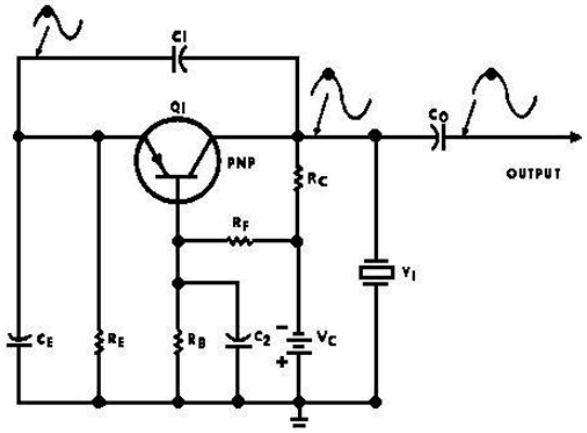


Figure 6-14. Pierce oscillator, common base configuration.

(2) Figure 6-15 shows the common emitter configuration of the Pierce oscillator. The resistors in the circuit provide the proper bias and stabilization conditions. The crystal unit and capacitors C1 and C2 determine the output frequency of the oscillator. The signal developed at the junction of Y1 and C1 is 180 degrees out of phase with the signal at the junction of Y1 and C2. Therefore, the signal at the Y1-C1 junction can be coupled back to the base of Q1 as a regenerative feedback signal to sustain oscillations.

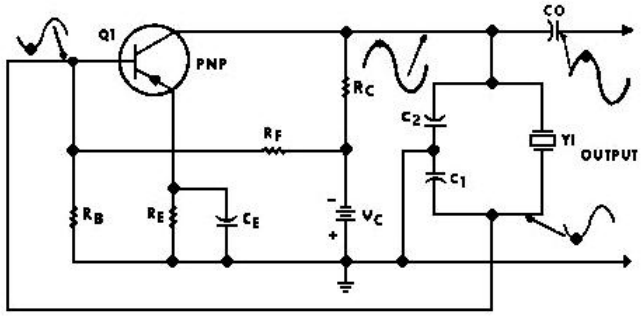


Figure 6-15. Pierce oscillator, common emitter amplifier configuration.

2. RESISTANCE-CAPACITANCE (RC) FEEDBACK OSCILLATORS.

a. Phase Shift Oscillator. The phase shift oscillator is a sine wave generator that uses a resistance-capacitance (RC) network as its frequency determining device. Besides determining the frequency, the RC network also provides the proper regenerative feedback to sustain oscillation.

(1) In any common emitter configuration (figure 6-16) there is a 180 degree phase difference between the base and collector signals. For regenerative feedback in the phase shift oscillator, a phase shift of 180 degrees between the output and input signals, is needed. An RC network consisting of three sections provides the proper feedback and phase inversion. Each section shifts the feedback signal 60 degrees in phase.

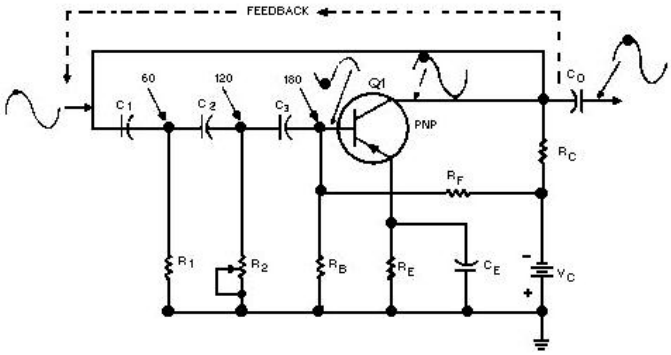


Figure 6-16. Phase shift oscillator.

(a) Since the impedance of an RC network is capacitive, current in it leads the applied voltage by a specific phase angle. The phase angle is determined by the amount of resistance and capacitance of the RC section. Different values of resistance and capacitance produce different phase angles.

(b) If the capacitance is a fixed value, a change in the resistance value will change the phase angle. If the resistance is changed to zero, a maximum phase angle of 90 degrees is developed. But since a voltage cannot be developed across zero resistance, a 90 degree phase shift is impossible.

(c) With a small value of resistance however, the phase angle or phase shift is less than 90 degrees. In the phase shift oscillator, therefore, at least three RC sections are needed to give the required 180 degree phase shift for regenerative feedback. The values of resistance and capacitance are generally chosen so that each section gives a 60 degree phase shift.

(2) In the figure, resistors RB, RF, and RC provide base and collector bias. Capacitor CE bypasses ac variations around swamping resistor RE. Capacitors C1, C2, and C3 and resistors R1, R2, and RB form the feedback and phase shifting network. Resistor R2 is variable for fine tuning to compensate for any small changes in value of the other components of the phase shift network.

(3) When power is applied to the circuit, oscillations are started by any random noise. A change in the flow of base current results in an amplified change in collector current, phase shifted 180 degrees. The signal returned to the base is inverted 180 degrees by the action of the RC network making the circuit regenerative. A, figure 6-17, shows the amount of phase shift produced by C1 and R1. B of the figure shows the amount of phase shift produced by C2 and R2 (signal received from C1 and R1), and C shows the complete phase shift as the signal leaves the RC network. With the correct amount of resistance and capacitance in the phase shift network, the 180 degree phase shift occurs at only one frequency. At any other than the desired frequency, the capacitive reactance increases or decreases and causes an incorrect phase relationship (the feedback becomes degenerative). Thus, the oscillator works at only one frequency.

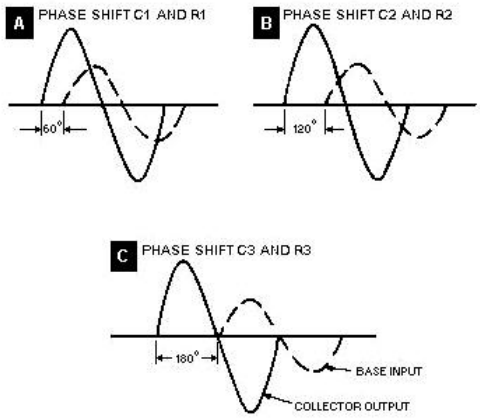


Figure 6-17. Three section phase shifting RC network.

(4) A high gain transistor must be used with the three section RC network because the losses in the network are high. Using more than three RC sections actually reduces the overall signal loss within the network. This is because additional RC sections reduce the phase shift necessary for each section, and the loss for each section is lowered as the phase shift is reduced. In addition, an oscillator that uses four or more RC networks has more stability than one that uses three RC networks. In a 4-part RC network each part shifts the phase 45 degrees to give the required 180 degrees phase shift.

b. Wein-Bridge Oscillator. Another circuit that uses a resistance-capacitance (RC) network to produce a sine wave output is the Wein-bridge oscillator. This oscillator is very stable and its output signal has a minimum of distortion with very little amplitude variation. These three features-frequency stability, minimum distortion, and amplitude stability--make the Wein-bridge oscillator extremely useful as a master timing oscillator.

(1) The Wein-bridge oscillator (figure 6-18) has two transistors connected in the common emitter configuration. In the phase shift oscillator one amplifier plus the phase shift network to produce the desired 360 degrees phase shift, is used. The amplifier produced the equivalent of a 180 degree phase shift and the RC network produced a 180 degree phase shift for a total of 360 degrees. Since one amplifier provides 180 degrees phase shift, two amplifiers can be used to get a 360 degree phase shift. The Wein-bridge oscillator, then, is basically two RC amplifiers with proper feedback. To obtain its desirable qualities, both regenerative and degenerative feedback are used.

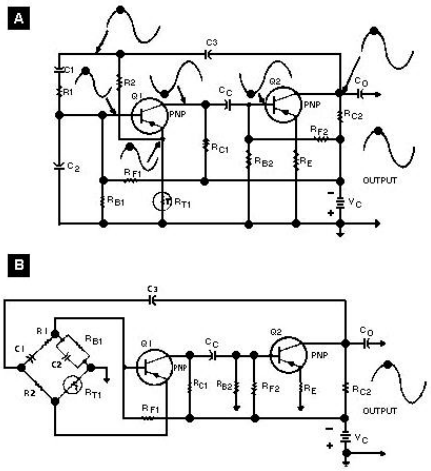


Figure 6-18. Transistor Wien-bridge oscillator.

(2) Although A and B, of figure 6-18, are essentially the same, A is arranged so the feedback path can be identified, and B is arranged so the components of the bridge network are shown. Both transistors Q1 and Q2 use the same type of biasing and stabilization. Resistors RB1 and RF1 establish bias for the base of Q1 and resistors RB2 and RF2 establish bias for the base of Q2. Resistor R2 and thermistor RT1 establish the feedback for degeneration in Q1. RT1 also acts as a swamping resistor. Resistor RE is left unbypassed to get degeneration and increased output waveform stability for Q2. Capacitor CC couples the output of Q1 to the base of Q2. Capacitor C3 couples the sine wave output to the next.

(3) The frequency of the Wein-bridge oscillator is determined by the values of capacitors C1 and C2, and resistors R1 and RB1. To operate the oscillator as a variable frequency selector bridge network. Oscillations start when power is applied. A charge in the base current of Q1 results in a amplified change in collector current, phase shifted 180 degrees. The signal is then applied to the base of Q2. The amplified output of Q2 is also phase shifted 180 degrees. The output of Q2 is then fed back to the base of Q1 to sustain oscillations.

(4) The frequency selector circuit (bridge network) in the feedback path prevents the output frequency from changing. The feedback signal is developed between the collector of Q2 and ground and is applied to the frequency selector circuit (A, figure 6-19).

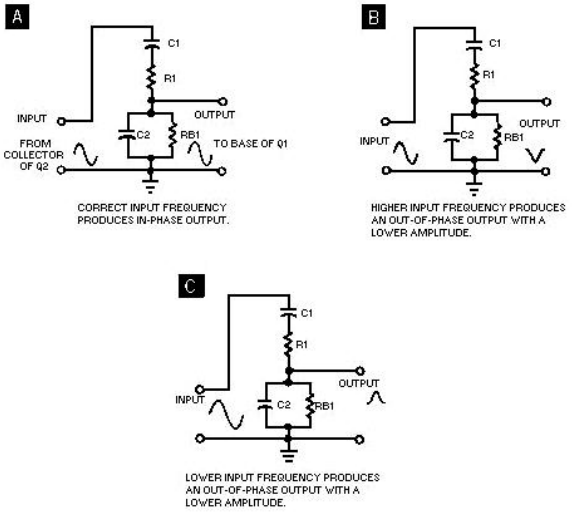


Figure 6-19. Frequency selector circuit simplified.

(a) An important point to remember about this circuit is that the output developed across C2 and RB1 is in phase with the feedback signal of Q2 at only one frequency. If the frequency applied to the frequency selector circuit increases, the signal across C2 and RB1 is affected in two ways (B, figure 6-19): the output signal will be out of phase with the incoming signal; and, its amplitude will decrease.

(b) If the input frequency decreases (C, figure 6-19), again there is an out-of-phase condition and a decrease in amplitude. Because of the action of the frequency selector, the signal at the base of Q1 will be in phase with the feedback signal at only one frequency. If a higher or lower frequency is fed back to the frequency selector, it will cause an out-of-phase signal with a much lower amplitude to be applied to the base of Q1. This in turn will prevent operation of the Wein-bridge oscillator circuit.

(c) At the resonant frequency, the phase shift is 360 degrees (or zero degrees). At frequencies above and below the resonant frequency, a phase difference occurs and a positive (regenerative) feedback voltage is greatly reduced in value.

(5) The degenerative or negative feedback circuit is simply a voltage divider consisting of R2 and RT1 (figure 6-18). The signal applied to this voltage divider is the same signal that is applied to the frequency selector circuit. The amplitude of the signal between R2 and RT1 is determined by their resistances.

(a) Notice that this signal is tapped from the voltage divider and applied to the emitter of Q1. The feedback voltage is determined primarily by resistor R2 (which can be made variable to control the output amplitude). Above or below the resonant frequency a greater negative feedback voltage is applied to the emitter with respect to the signal applied to the base.

(b) Therefore, if the feedback signal contains other than the resonant frequency, the emitter voltage will be high while the base voltage will be low. The degenerative effect will cancel out all frequencies except the resonant frequency, providing a highly stable oscillator.

(6) The emitter resistor of Q1 is a thermistor, with a positive temperature coefficient of resistance. In some circuits a lamp may be substituted for the thermistor. In either case, its function is to stabilize the output amplitude of the oscillator.

(a) When the amplitude of the output signal increases above its predetermined range, an increased feedback voltage results. As a result of the increased feedback voltage, the current through the thermistor will increase, the resistance of the thermistor will increase, which, in turn, causes an increase in the negative feedback voltage.

(b) This reduces the gain of the amplifier and effectively returns the output voltage to its correct level. Therefore, additional amplitude stabilization is provided. In Wein-bridge oscillators that do not need this additional stability, an ordinary resistor may be used as the emitter resistor.

3. FREE-RUNNING NONSINUSOIDAL OSCILLATORS.

a. General.

(1) An oscillator that has a nonsinusoidal output waveform is called a relaxation oscillator. The relaxation oscillator uses a regenerative circuit in conjunction with resistance-capacitance (RC) components to provide a switching action. The charge and discharge of the capacitors are used to produce either sawtooth, square, or other pulse-shaped output waveforms. Multivibrators and blocking oscillators are examples of relaxation oscillators and they are further classified as either free running or drive (triggered). A free-running multivibrator is one in which the oscillations begin once power is applied; the oscillations then become continuous while the circuit is in operation. Triggered multivibrators are controlled by synchronizing or external trigger signals.

(2) The following properties of a transistor amplifier circuit are used in multivibrator and blocking oscillator circuits. These properties apply to the common emitter configuration; it is used because it has 180 degrees phase shift between its input and output signals.

(a) An increase in the emitter-to-base forward bias causes an increase in collector current. A decrease in the emitter-to-base forward bias causes a decrease in collector current.

(b) An increase in collector current causes the collector voltage to decrease. A decrease in collector current causes the collector voltage to increase towards the value of the source voltage.

(c) A transistor is saturated when a further increase in base current causes no further increase in collector current.

(d) A transistor is cut off when either the base voltage polarity is reverse biased, or the collector voltage polarity causes reverse bias.

(e) Capacitors require a definite amount of time to charge or discharge through a resistor. The measure of this time, called the time constant, is determined by multiplying the resistance by the capacitance.

b. Free-Running Multivibrators. The free-running or astable multivibrator is essentially a nonsinusoidal, two-stage oscillator. Astable means that it has two stable states as explained below. In this multivibrator, one stage conducts until a point is reached at which the stages reverse their conditions. That is, the conducting stage cuts off and the other (cutoff) stage begins conducting. This on-off process oscillates back and forth between the two stages and results in a square or pulse-shaped output. The shape of the output depends on the oscillator circuitry.

(1) The basic collector-coupled multivibrator is a two-stage RC coupled common-emitter amplifier. The output of the first stage is coupled to the input of the second stage, and the output of the second stage is coupled to the input of the first stage (figure 6-20). Since the signal in the collector circuit of a common-emitter amplifier is reversed in phase with respect to its input, a portion of the output of each stage is fed to the other stage in phase with the signal on the base electrode. This regenerative feedback with amplification is required for oscillation. Bias and stabilization are established identically for both transistors. Because of the variation in tolerances of the components, one of the transistors will either conduct before the other, or conduct more heavily than the other.

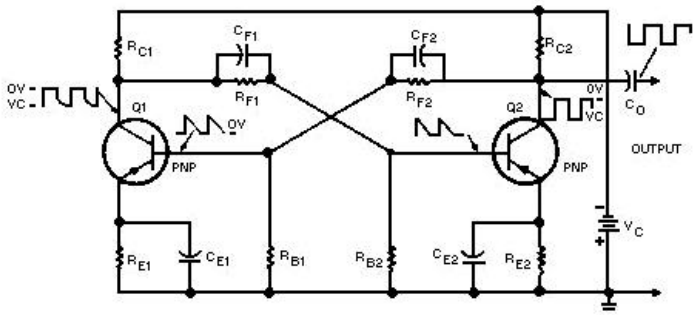


Figure 6-20. Free-running multivibrator.

(2) Assuming transistor Q1 is conducting more heavily than transistor Q2, more current will flow in the base circuit of Q1 than in the base circuit of Q2. Collector current of Q1 increases rapidly, causing its collector voltage and the voltage at the junction of resistors RC1 and RF1 to decrease (become more positive). This increasing positive voltage is applied through capacitor CF1 to the base of Q2.

(a) As the base voltage of Q2 becomes more positive, its forward bias decreases, resulting in a rapid decrease in its base and collector currents. The collector voltage of Q2 and the voltage at the junction of resistors RC2 and RF2 becomes more negative. This negatively increasing voltage is fed back through capacitor CF2 to the base of Q1, increasing its forward bias. This process continues until a point is reached where the base voltage of Q2 is made so positive with respect to its emitter that Q2 is cut off (reverse bias is applied) and Q1 is saturated. That is, the current through Q1 increases steadily as the current through Q2 decreases steadily until Q2 is cut off.

(b) Point A, figure 6-21, represents this action. The entire action happens so quickly that CF1 does not get a chance to discharge and the increased positive voltage at the collector of Q1 appears entirely across resistor RB2.

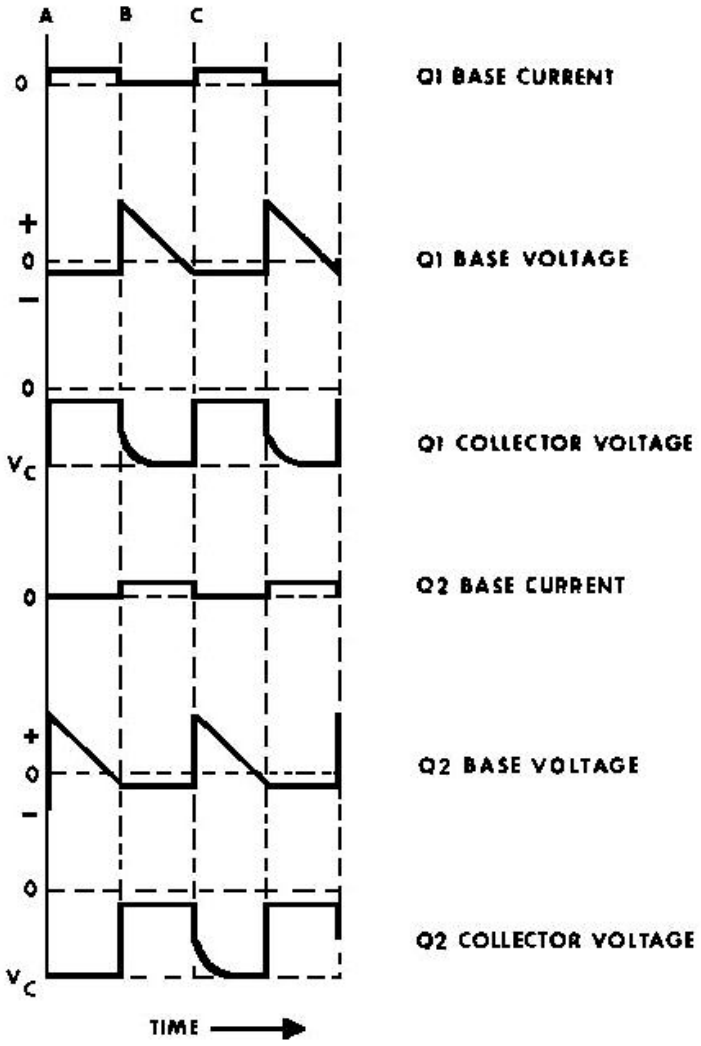


Figure 6-21. Collector coupled multivibrator waveforms.

(c) During the period from A to B, the collector current and voltage of Q1 remain constant. Capacitor CF1 discharges through resistor RF1 and, as it does, the signal at the base of Q1 is at its most positive value. As CF1 continues to discharge, the signal at the base of Q2 decreases to a negative value, decreasing the reverse bias on the base of Q2. This action continues until the time at point B when forward bias is reestablished across the base-emitter of Q2.

(3) Transistor Q2 conducts and as its collector current increases, its collector voltage becomes less negative (more positive). This voltage, coupled through capacitor CF2 to the base of Q1, drives the base positive and causes a decrease in current through Q1. The resulting increased negative voltage at the collector of Q1 is coupled through capacitor CF1 and appears across resistor RB2. Therefore, the collector current of transistor Q2 increases. This process continues rapidly until Q1 is cut off. Transistor Q1 remains cut off (and Q2 conducts) until CF2 discharges through RF2 enough to decrease the reverse bias on the base of Q2 (point C, figure 6-21). The cycle is then repeated.

(4) The oscillating frequency of the multivibrator is usually determined by the values of resistance and capacitance in the circuit. In the collector-coupled multivibrator, collector loads are provided by resistors RC1 and RC2. Base bias for transistor Q1 is established through voltage divider resistors RB1 and RF2. Base bias for transistor Q2 is established through voltage divider resistors RF1 and RF2. Stabilization is obtained with emitter swamping resistor RE1 for Q1, and RE2 for Q2. Capacitors CE1 and CE2 are emitter bypass capacitors. The output signal is coupled through capacitor Co to the next stage. The output waveform, which is essentially square, may be taken from the collector of either transistor Q1 or Q2.

c. Saturable-Core Square Wave Oscillator. Transistors, functioning as high-speed switching elements; may be used in conjunction with transformers. Transistors can function as either switches or relays, and they switch from cutoff to saturation (open and close) faster than mechanical devices. This circuit operates with greater efficiency and at higher frequencies than the common mechanical vibrator used in portable power supplies. The output square wave may be stepped up or down and then rectified, providing a higher or lower dc voltage than the available power source. When the circuit is used with a full-wave rectifier, very little filtering is required because of its high frequency and square wave output.

(1) The switching action that occurs in a mechanical vibrator circuit is shown in A, figure 6-22. Vibrator contacts are simulated by ganged switches S1 and S2. The operation is such that when one is opened the other switch is closed. When switch S1 is closed, the battery voltage is applied across the 1-2 winding of transformer T1. The polarities of the voltages induced in the other windings are as indicated. When the switch operation is reversed, the battery voltage is applied across the 3-4 winding and the polarity is reversed. The voltage across secondary winding 5-6 will also be reversed from the first condition. When the mechanical switching is rapid, a voltage waveform across the load resistor RL will essentially be square wave as shown in B of the figure.

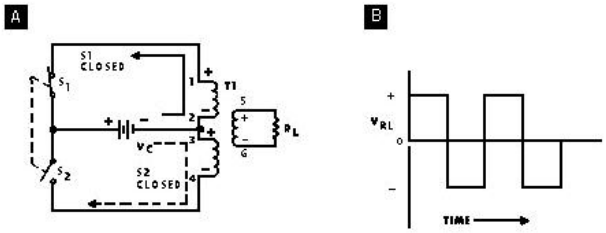


Figure 6-22. Mechanical switching circuit.

(2) Basically, the operation of the saturable-core square wave oscillator (A, figure 6-23) depends on the switching action of transistors Q1 and Q2. When Q1 conducts heavily, it may be compared to closing switch S1 (A, figure 6-22). At the same instant of time, Q2 will be cutoff (similar to switch S2 being open). The transition from cutoff to heavy conduction and vice versa is extremely rapid and gives a square wave output.

(a) Starting oscillations in the circuit depends on the unbalance existing between the apparently identical circuits of Q1 and Q2. This is due to a small unbalance in both external circuits and the transistors themselves. Because of this small unbalance, more current will flow in one of the primary windings of transformer T1 than in the other. For this example the assumption is that more current flows through 3-4 winding.

(b) The starting point will be at point F (negative saturation region of flux in the transformer core) on the hysteresis curve (B, figure 6-23). Transistor Q1 conducts heavier and the core flux moves from point F toward point B (positive saturation region), inducing a voltage in all other windings. Since the collector circuit current is from the negative terminal of the source voltage, the induced voltages will be positive at the top of each winding in A, figure 6-23. Notice that the base of Q1 is made more negative, driving it to heavy conduction. The base voltage of Q2 is made more positive, driving it to cutoff.

(c) The flux in the core changes at a relatively constant rate until point B is reached. At core saturation (point C), any further increase in current does not increase the flux in the core. Since the flux remains constant, no further voltage is induced in the primary and secondary windings of T1. The induced voltages quickly fall to zero and remove the negative potential from the base of Q1. Q1 will stop conducting and prevent current flow in the 3-4 winding of T1.

(3) When current ceases in the 3-4 winding, the flux of the core falls from point C towards point A (B, figure 6-23). Due to this small decrease of flux, voltages of opposite polarity of those that previously existed are induced in all of the transformer windings. Transistor Q1 will be driven further into cutoff by the positive voltage now applied to its base. The flux of the transformer core will go towards negative saturation (point A to point E). During this period, Q1 is at cutoff and Q2 conducts heavily. Once point D is reached on the curve, any further increase in current will not cause an increase in flux in the negative saturation region. The switching of Q1 from cutoff to conduction and Q2 from conduction to cutoff occurs. The cycle then continues to repeat itself.

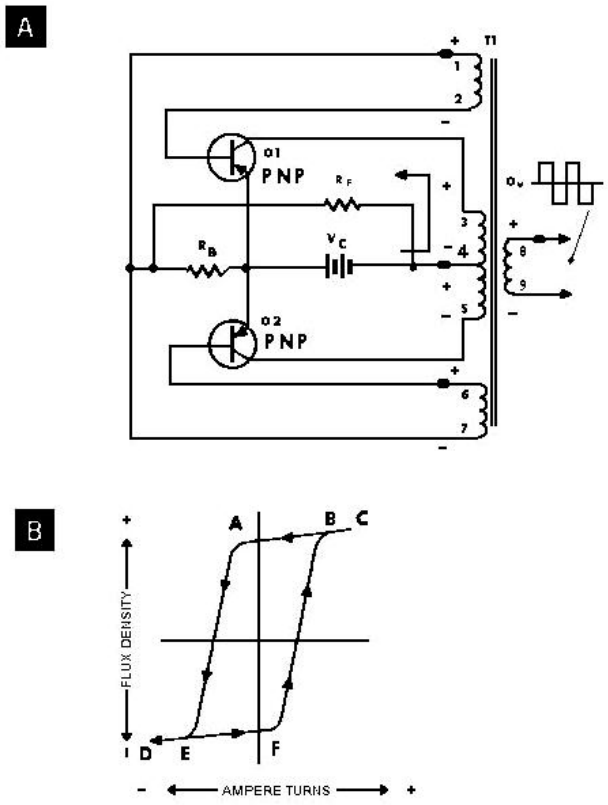


Figure 6-23. Saturable-core square wave oscillator.

(4) The output voltage developed across winding 8-9 is essentially a square wave. This occurs because the core flux changes at a relatively constant rate from points F to B and from A to E (B, figure 6-23). The output frequency and voltage are determined by the turns ratio of the primary and secondary windings of transformer T1, and by the saturation flux of the transformer core. Resistors RB and RF establish the initial bias voltages for the bases of transistors Q1 and Q2.

d. Blocking Oscillator. A blocking oscillator is often used as a master oscillator in equipment. It is capable of generating pulses of very short duration that can be used to trigger and synchronize other circuits in the equipment. Blocking oscillators may be either free-running or triggered.

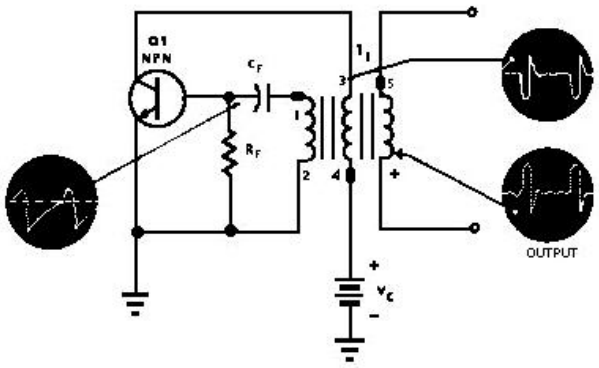


Figure 6-24. Blocking oscillator.

(1) In the blocking oscillator circuit in figure 6-24, when voltage Vc is applied to transistor Q1 it starts to conduct. Collector current flows through the primary winding 3-4 of transformer T1. The magnetic field that builds up across the primary winding induces a voltage into the other two windings. This results in a positive voltage on terminal 1 of T1 which is coupled through capacitor CF and causes Q1 to go into saturation. (The output voltage on terminal 5 also goes positive at this time.) Capacitor CF charges quickly through the low emitter-to-base junction resistance of Q1, and assume the charge shown in A of figure 6-25. When Q1 reaches saturation, collector current stops increasing and remains at a constant value. Since current through transformer winding 3-4 remains constant, the magnetic field starts to collapse and capacitor CF starts to discharge through resistor RF (B, figure 6-25).

(2) When capacitor CF discharges through resistor RF it causes the base of the transistor to become negative and drives the transistor into cutoff. The capacitor discharging through the resistor (a long time constant) keeps the transistor cut off. Then, when the capacitor is almost discharged, the reverse bias is removed from the base and the transistor starts conduct again. This action keeps repeating itself and produces an output of sharp narrow pulses that can be used to trigger other circuits.

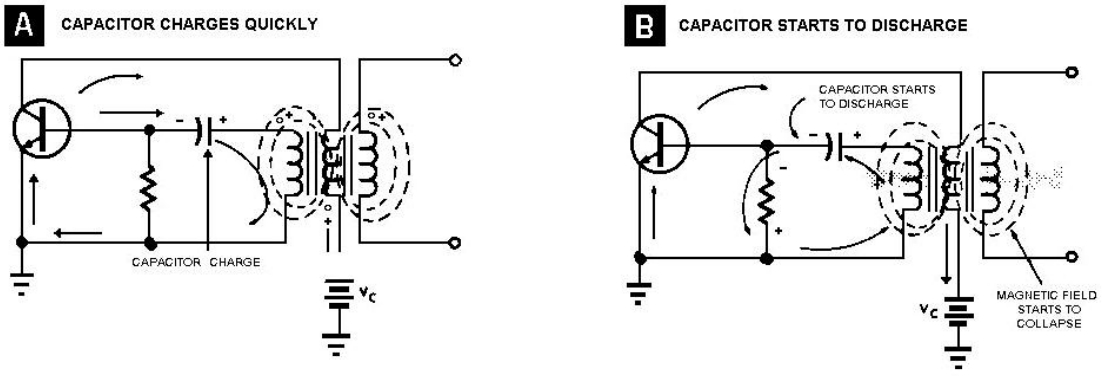


Figure 6-25. Charge and discharge of blocking oscillator capacitor.

MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS

EXERCISES FOR LESSON 6

1. What type of oscillator is know as a tickler coil tuned base?

   A. Hartley
   B. Colpitts
   C. Crystal
   D. Armstrong

2. Which is not a requirement for an oscillator?

   A. Regenerative feedback
   B. Phase inversion
   C. Amplification
   D. Frequency control device

3. What circuit(s) use split capacitor circuits for feedback in figure 6-2?

   A. C
   B. G&H
   C. E&F
   D. B

4. What components of figure 6-3 provide the necessary bias conditions in the Armstrong oscillator?

   A. RF, RC, and RB
   B. Cc, RE, and RF
   C. RE, RC, and RF
   D. RB, RC, and RE

5. What component provides the Armstrong oscillator in figure 6-3 regenerative feedback?

   A. RC
   B. C2
   C. Action of coils L1 and L2
   D. Cc

6. Where is the frequency determining circuit located in the Armstrong oscillator shown in figure 6-5?

   A. Base of Q1
   B. Emitter Q1
   C. Across RB and CB
   D. Collector of Q1

7. What is the main difference between the Hartley and Armstrong oscillators?

   A. The Hartley oscillator uses a transformer
   B. The Hartley oscillator does not use an amplifier
   C. The Armstrong oscillator uses a split inductor coil in the tank circuit for feedback
   D. The Hartley oscillator uses a split inductor coil in the tank circuit for feedback

8. What components make up the tank circuit of the series-fed Hartley oscillator shown in figure 6-6?

   A. L1 and C2
   B. L1 and L2
   C. L1, L2, and C2
   D. L1, L2, and C1

9. What is the relationship between mechanical and electrical effects of a crystal known as?

   A. Resonant frequency
   B. Piezo-electric
   C. Frequency synthesis
   D. Frequency stability

10. What is the main difference between the Colpitts and the Clapp oscillators?

   A. Addition of a variable capacitor in parallel with the inductance of the tank circuit in the Colpitts oscillator
   B. Addition of a variable capacitor in series with the inductance of the tank circuit in the Colpitts oscillator
   C. Addition of a variable capacitor in series with the inductance of the tank circuit in the Clapp oscillator
   D. Elimination of the tank circuit in the Clapp oscillator

11. What is the purpose of variable capacitors C1 and C2 in figure 6-9?

   A. Control the frequency of the oscillator
   B. Provide feedback for the circuit
   C. Control the gain of Q1
   D. Eliminate noise in the circuit

12. Where does the input, if any, enter the phase shift oscillator shown in figure 6-16?

A. Between R1 and ground
B. There is no input; oscillations start when power applied by random noise
C. Between RB and ground
D. At C1 and ground

13. Which statement is correct?

A. In a parallel tuned circuit there is minimum impedance at resonance
B. In a series tuned circuit there is maximum impedance at resonance
C. At resonance minimum impedance is felt in a series tuned circuit
D. In a parallel tuned circuit acts inductively above parallel resonance

14. What is the minimum amount of RC sections necessary to get 180 degrees phase shift in a phase shift oscillator?

A. 1
B. 2
C. 3
D. 4

15. What components located on figure 6-18 determine the frequency of the Wein-bridge oscillator?

A. CC and RB2
B. C2, RB1, R1, C1
C. C1, C2, RT1, and R2
D. C1 and R2

16. What is another name for the nonsinusoidal oscillator?

A. Relaxation
B. Phase shift
C. Shunt-fed
D. Series-fed

17. What best describes the free-running multivibrator?

A. Stable two-stage oscillator
B. Tuned two-stage oscillator
C. Astable two-stage oscillator
D. Nonsinusoidal two-stage oscillator

18. Using a CE configuration of a transistor amplifier in a blocking oscillator circuit, what statement is true?

A. When the base voltage polarity is reverse biased the transistor is saturated
B. An increase in collector current causes the collector voltage to increase
C. When the collector voltage polarity causes reverse bias the transistor is cutoff
D. Saturation of a transistor when increase in base current causes decrease in collector current

19. When the voltage on the base of Q1, figure 6-20, goes positive, the collector voltage of Q2

A. goes positive.
B. goes negative.
C. remains the same.
D. goes to zero volts.

20. What resistor(s) on figure 6-20 provide the collector load for transistor Q1?

A. RC1 and RF1
B. RF1
C. RF1 and RB2
D. RC1

21. What is the prime reason transistors are preferred over a common mechanical vibrator for switching purposes?

A. Smaller in size
B. Operate faster
C. Never need filtering
D. Longer life expectancy

22. When power is applied to the saturable-core square wave oscillator, on figure 6-23, which transistor will conduct first?

A. Q1
B. Q2
C. Neither; only when input square wave is applied
D. Either; although both have identical circuits, one must have a small unbalance and this determines the transistor that conducts

23. When Q1 of figure 6-23 is conducting, what are the polarities felt on the bases of Q1 and Q2?

A. Positive on Q1 and negative on Q2
B. Both positive
C. Negative on Q1 and positive on Q2
D. Both negative

24. What type of oscillator usually produces a trigger or synchronizing pulse?

A. Clapp
B. Blocking
C. Saturable-core
D. Wein-bridge

25. On figure 6-24, if the output at pin 5 of the transformer is going positive, what will be the operating condition of Q1?

A. Cutoff
B. Saturation
C. Barely conducting
D. Conducting at a high rate

LESSON 7. TRIGGERED AND GATING CIRCUITS

MMS Subcourse Number 701..... Transistors and Semiconductors

Lesson Objective..... To provide the student with a general knowledge of transistor switching characteristics and triggered circuits.

Credit Hours..... Four

TEXT

1. TRANSISTOR SWITCHING CHARACTERISTICS.

a. General.

(1) Pulse and switching circuits are used in radar, television, telemetering, pulse-code communication, and computing equipment. The circuits function as generators, amplifiers, inverters, frequency dividers, and wave shapers and they provide limiting, triggering, and gating and signal routing actions. Pulse and switching circuits are normally characterized by large-signal (nonlinear) operation of the transistor. Operation of these circuits is normally governed by the application of a pulse; or a change in the level of voltage or current applied to the circuit. The input signals (trigger pulses) produce output signals having large and sudden changes in voltage or current. Such nonlinear operation results in an output waveform which may differ considerably from the input waveform.

(2) Examples of pulse waveforms encountered in large-signal operation of the transistor are shown in figure 7-1. The changes in voltage levels with time are considered instantaneous, and represent a theoretical or ideal pulse. A voltage which undergoes an instantaneous change in amplitude from one constant level to another is called a unit step voltage. In pulse and switching circuit applications when the unit step voltage is the result of an applied signal, it is usually of sufficient magnitude to cause the circuit to change from a state of conducting to one of cutoff or vice versa. When the unit step voltage is the result of an applied signal to a switching circuit, the circuit has changed its state.

(a) A, figure 7-1, illustrates a positive unit step voltage. At time T1, the voltage level is increased (positively) by the amount V. The voltage level does not have to necessarily increase from zero to a positive voltage. If the initial voltage level is a negative potential and then changes to zero, a positive unit step voltage occurs.

(b) B of the figure represents a negative unit step voltage. At time T2, the voltage level is decreased (negatively) by the amount V. In this instance, the change in level could be either from a high positive potential to one that is less positive, or a change from zero to a negative level, or from a negative level to a higher negative level.

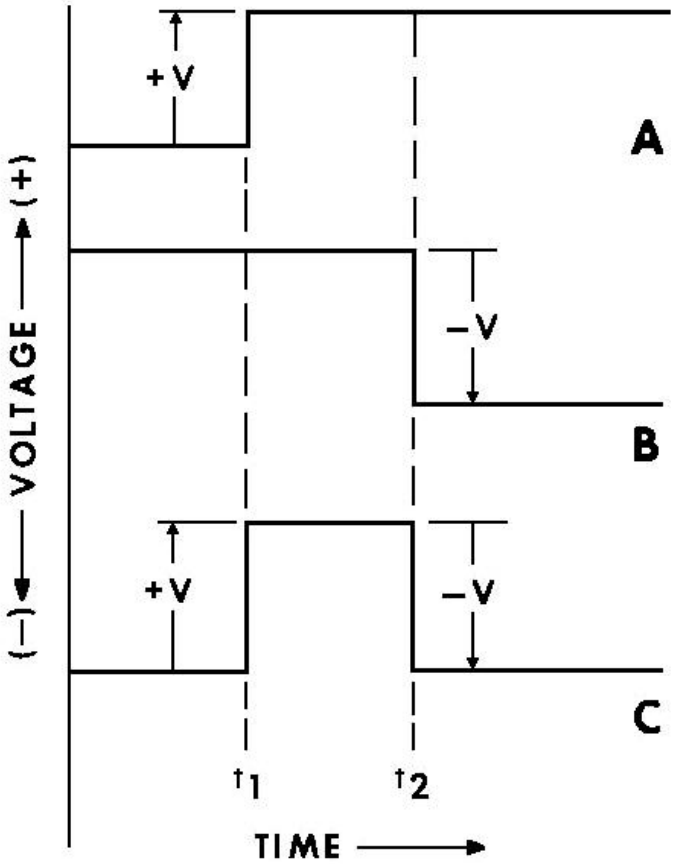


Figure 7-1. Unit step voltage waveforms, showing formation of a pulse.

(c) C, figure 7-1, shows a square or rectangular pulse. At time T1, the voltage level is increased by the amount V. Between time T1 and T2, a new constant voltage level is established. At time T2, the voltage level is decreased by the amount V. The square pulse may be referred to as two unit step voltages, one positive and one negative. Explanation of a unit step current is identical with that of unit step voltage. Current levels, rather than voltage levels, undergo instantaneous changes, either positively or negatively.

b. Large-Signal Operation.

(1) During large-signal (nonlinear) operation, a transistor acts as an overdriven amplifier. An overdriven amplifier can be compared to a switch or relay and has three comparable states of operation. A transistor is considered in the "off" state when it is not conducting. This is its cutoff region of operation. A transistor is considered in the "on" state when it is conducting and this is its saturation region of operation. The cutoff and saturation regions are considered to be stable regions of operation in which a slight change in the applied voltage has no significant effect on the amount of conduction.

(2) The third region of operation compares to the state of a switch when it is in the process of changing--it's between on and off. This is referred to as the active region of a switching transistor and it is very unstable. It is this unstable or transient region through which the transistor passes while changing from the off to the on state, and from the on to the off state.

c. Transistor Switching Circuit. A typical transistor switching circuit is shown in A, figure 7-2. Switch S1 controls the polarity of the applied base voltage from battery VB1 or VB2. Resistors RB1 and RB2 are current-limiting resistors. Ideally, with no applied voltage and no initial base current, there is zero collector current. The collector voltage equals battery voltage Vc and this is also the output voltage. Normal quiescent conditions for a transistor switch in the cutoff region require that the emitter-base junction be reverse biased.

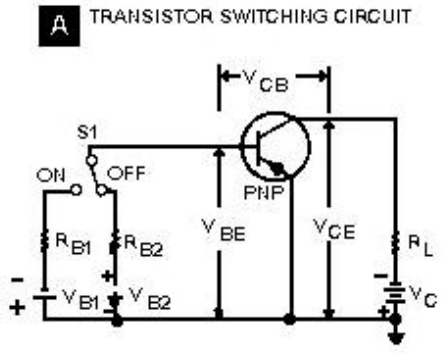


Figure 7-2a. Transistor switching circuit.

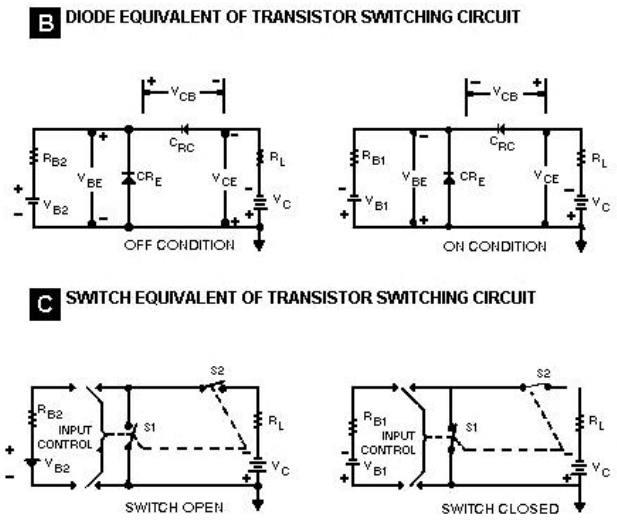


Figure 7-2b. Transistor switching circuit.

(1) With switch S1 in the OFF position, the emitter-base junction is reverse biased by battery VB2 through resistor RB2. This is comparable to the application of a positive unit step voltage and collector-emitter voltage VCE (output voltage) equals collector battery voltage Vc. The transient is in the OFF (cutoff) condition.

(a) In the diode equivalent circuit of the transistor switching circuit (B, figure 7-2), diodes CRE and CRC represent the emitter-base and collector-base junctions, respectively. Diode CRE is reverse biased by voltage VBE; diode CRC is reverse biased by voltage VCB.

(b) Ideally there is no current through load resistor RL and collector-emitter voltage VCE (output voltage) equals collector battery voltage VC. The circuit, as a switch, is open (C, figure 7-2).

(2) Operation of switch S1 to the ON position is comparable to the application of a negative unit step voltage. Forward bias on the emitter-base junction is established by battery VB1 through resistor RB1 and collector current reaches saturation. At this point the output voltage is zero because the transistor (at saturation) has negligible resistance. The transistor is in the ON (conducting) condition.

(a) In the diode equivalent circuit of the transistor switching circuit (B, figure 7-2), diodes CRE and CRC are forward biased. Diode CRE is forward biased by input voltage VBE. Voltage VCE drops to a smaller negative value than input voltage VBE; the difference in potential of these voltages causes the forward bias (VCB) on diode CRC.

(b) The equivalent switch circuit (C, figure 7-2) is closed. Switches S1 and S2 close the circuit for battery VC through load resistor RL. The circuit may also be switched from the on state to the off state in a similar manner. Small input voltage or current pulses may be used to control large output voltage or current pulses.

d. Three Regions of Operation.

(1) Active region. The active linear region is the only region of normal amplification. If only enough voltage is applied to drive the transistor into this region, it would act similar to a normal amplifier. A slight change in applied voltage would cause a large change in the output voltage. Due to the design of the transistor, only a moderate amount of voltage change (approximately 3 volts or less) in the applied signal is required to drive the transistor from cutoff to saturation, or to return it to cutoff. Therefore, the output signal passes through the active region very rapidly. In switching circuits, this active region is important because it determines the switching speed of the circuit.

(2) Saturation region. In the saturation region, an increase in base voltage does not cause an appreciable increase in collector voltage. Collector voltage VCD is at a minimum. This value of collector voltage is referred to as the saturation voltage, and is an important characteristic of the transistor. Deep saturation is generally avoided because it requires a large change in voltage to bring the transistor out of saturation. This produces a poor transient response. When collector current reaches its limited value the transistor is saturated and is in the on or conducting state.

(3) Cutoff region. The cutoff region is quite stable, much the same as the saturation region. When the base-emitter junction is reverse biased, the transistor conducts so little that it is said to be cut off. Any additional voltage that increases the amount of reverse-biasing has little effect.

e. Transistor Configuration As Switches. Regions of operation are similar for all transistor configurations used as switches. When the base-emitter junction of a transistor is reverse biased (cutoff condition), the output current is very low and the output voltage is high. When the base-emitter junction is forward biased (saturated condition), the output current is high and the output voltage is low.

(1) Common base. For large-signal operation, the common base (CB) configuration acts as a series switch. The output (collector) current is essentially a large percentage of the input (emitter) current. For practical purposes, these currents may be considered equal. The transient response of this configuration is better than that of the other configurations and makes the CB configuration best for use in high-speed switching circuits. In addition, its low input resistance and high output resistance make it effective for impedance matching purposes.

(2) Common emitter. When used in pulse and switching circuits, the common emitter (CE) circuit acts as a shunt switch. That is, the input (base) current acts only to regulate or control the output (collector) current. Because the transient response of the CE configuration to an input pulse is poorer than that of the CB configuration, it causes a large drop in current gain at high frequencies. Thus, the CE configuration is generally used at lower frequencies more than the CB configuration (assuming the same type of transistor is used). Despite its lower frequency response, however, the CE configuration is preferable in many applications because of its high power gain. In addition, only this configuration provides phase inversion.

(3) Common collector. The common collector (CC) configuration is an emitter follower circuit. Similar to the CE configuration, it functions as a shunt switch. Its voltage gain is essentially unity. The properties of a high input impedance and low output impedance of the CC circuit in its active region make it generally useful as a buffer and for impedance matching.

f. Large-Signal Pulse Characteristics. When switch S1 in A, figure 7-2, is operated in sequence from OFF to ON and then back to OFF, the resultant input current pulse is similar to that in A, figure 7-3. In large-signal operation, a rectangular input signal drives the transistor from cutoff to saturation and back to cutoff. The distorted output current pulse (B, figure 7-3) results because the transistor cannot respond instantaneously to a change in signal level. The response of the transistor during rise and fall time is called the transient response of the circuit.

(1) Rise time. The rise time (Tr, also referred to as build-up time or turn-on-time) is the time required for the leading edge of the pulse to increase in amplitude from 10 to 90 percent of its maximum value. Nonlinear characteristics of the transistor, the external circuit, and energy storage effects all contribute to the time. Carriers moving from emitter to collector collide and disperse and do not reach the collector at the same time. Overdriving the transistor results in decreased rise time.

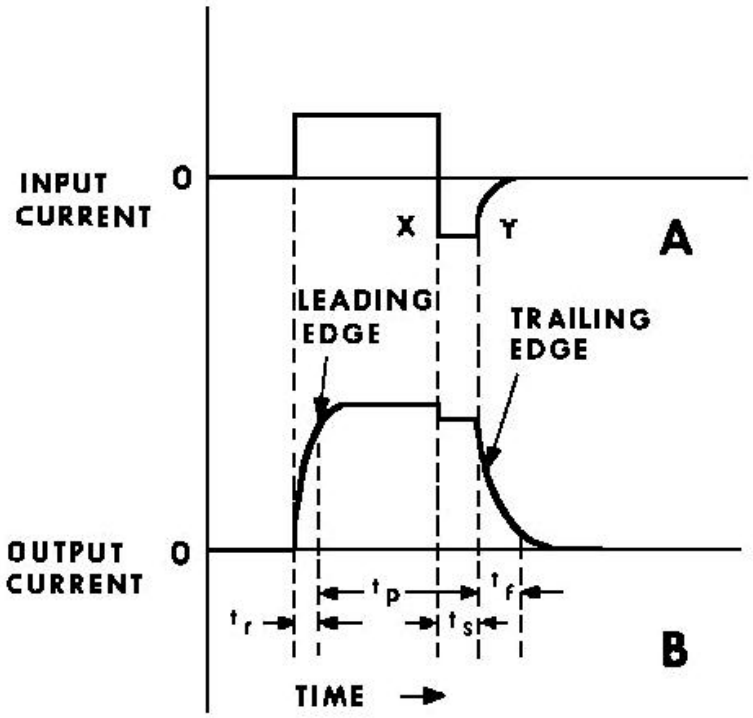


Figure 7-3. Current pulse characteristics, switching circuit.

(2) Pulse time. The pulse time (Tp), or duration time, is the length of time that the pulse remains at, or near, its maximum value. The pulse time duration is measured from the point on the leading edge where the amplitude of the pulse has reached 90 percent of its maximum value to the point on the trailing edge where the amplitude falls to 90 percent of its maximum value.

(3) Storage time (minority carrier storage). When the input current is cut off, the output current does not immediately fall to zero, but remains almost at its maximum value for a length of time before falling to zero. This period is called the storage time (Ts) or saturation delay time. Storage time results from injected minority carriers being in the base region of the transistor at the moment when the input current is cut off. These carriers require a definite length of time to be collected. The length of storage time is essentially governed by the degree of saturation into which the transistor is driven and the time spent in saturation. The base current reversal that occurs between points X and Y, at the end of the input pulse, is the result of the stored current carriers.

(4) Falltime. During the fall (tf) or decay time of the pulse, the amplitude falls from 90 to 10 percent of its maximum value. The falltime of the pulse is essentially determined by the same factors that determine its rise time. Falltime may be slightly reduced through the application of a reverse current at the end of the input pulse.

g. Diode Limiters and Clippers. There is a wide variety of circuits used to control signal amplitudes and voltage levels; they are called limiters and clippers. The distinction between limiters and clippers is difficult to determine and therefore these circuits are called by either name because basically, they perform similar functions. For purposes of this discussion, call the circuit either a limiter or clipper, based on the following definitions.

(1) A limiter is a circuit in which the output voltage is proportional to the input voltage up to a predetermined level, and is maintained at a constant value for all input voltages above this level. A, figure 7-4, shows a limiter input-output characteristic graph in which the output voltage never exceeds +5 volts. When the input voltage is -3 volts, the output voltage is -3 volts. When the input voltage is increased to +3 volts, the output voltage is +3 volts, and so on up to +5 volts. All input voltages above +5 volts appear at the output as +5 volts.

(2) A clipper is a circuit in which the output voltage is proportional to the input voltage at a predetermined level, and is maintained at a constant value for all input voltages below this level, B, figure 7-4, shows a clipper input-output characteristic graph in which the output voltage never drops below -1.5 volt. It shows that when the input voltage is +6 volts, the output voltage is +6 volts. When the input voltage is +2 volts the output voltage is +3 volts and so on down to -1.5 volt. At input voltages below -1.5 volt, the output voltage remains at -1.5 volt.

(3) A limiter-clipper circuit acts as both a limiter and clipper. In this circuit the output voltage is held constant at both the higher and lower levels of the predetermined limiting and clipping levels. C, figure 7-4, shows a limiter-clipper characteristic graph. If the input voltage rises above +5 volts, it is limited at the +5 volt level. If the input voltage decreases to less then -3 volts, it is clipped at the -3 volt level.

(4) The input signal to limiter/clipper circuits may be a positive signal, a negative signal, or a combined signal having either the same or different waveforms on either the positive or negative alternation. The output signal may be a positive signal with the negative portion completely eliminated; or, a negative signal with the positive portion completely eliminated. The output signal may contain only a portion of the positive peaks with the remainder of the positive and all of the negative signal eliminated. It may contain only a portion of the negative peak with the remainder of the negative and all of the positive signal eliminated. Finally, the output signal may contain both positive and negative signals with both the positive and negative peaks eliminated.

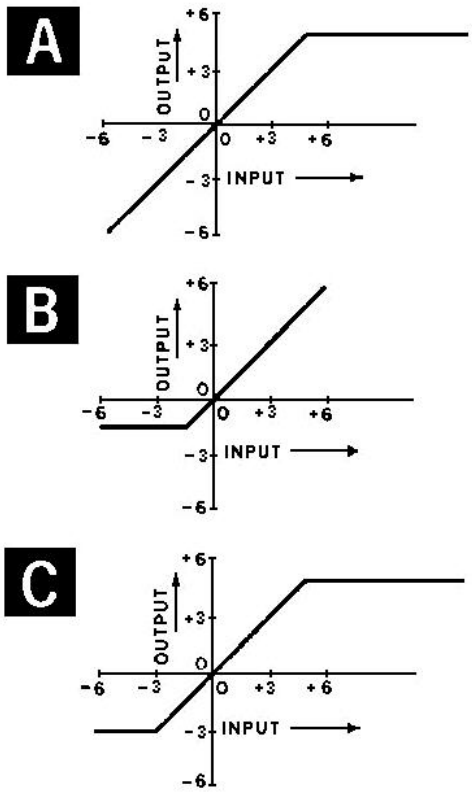


Figure 7-4. Limiter, clipper, and limiter-clipper input-output.

h. Series Diode Limiter And Clipper.

(1) Series diode limiter. This circuit is called a series circuit because diode CR1 (A, figure 7-5) is in series with the output. Current must flow through the diode to produce an output voltage. In order for the diode to conduct, the anode must be more positive than the cathode. When the input signal contains a positive pulse (B, figure 7-5), the diode is reverse biased because the cathode is more positive than the anode and no current flows through the diode or through resistor R1. When the input signal goes negative the cathode is more negative than the anode and the diode conducts. Current through R1 produces the waveform shown in C, figure 7-5.

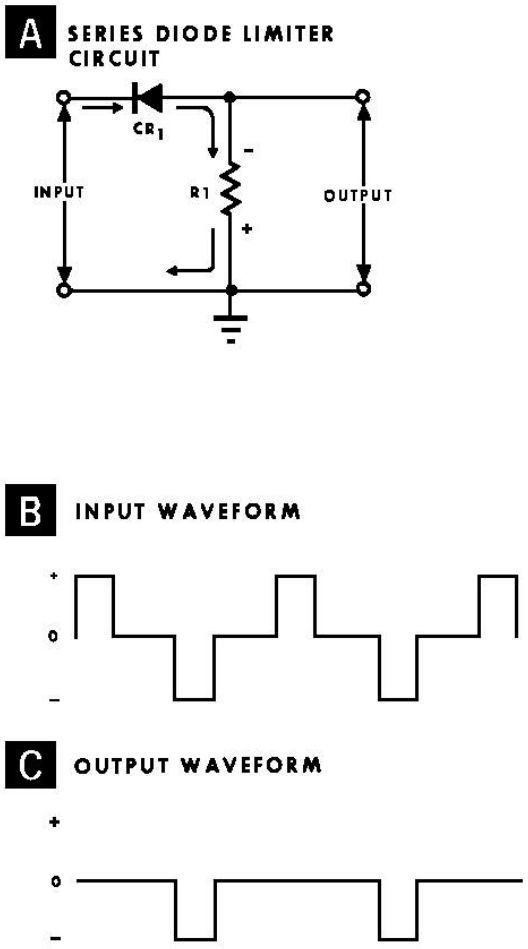


Figure 7-5. Series diode limiter.

(2) Series diode clipper. If diode CR1 is reversed (A, figure 7-6), the circuit now becomes a series diode clipper. When the applied input voltage (B, figure 7-6) is positive the anode is more positive than the cathode and current flows through R1 and CR1. The output waveform (C, figure 7-6) contains the positive going pulse. When the input signal swings negative, CR1 is reverse biased and no current flows through R1.

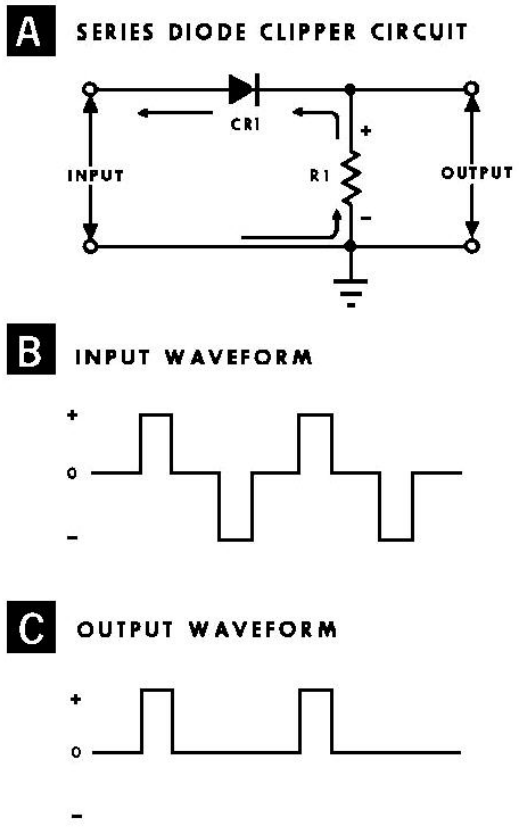


Figure 7-6. Series diode clipper.

i. Parallel Diode Limiter And Clipper.

(1) Parallel diode limiter. This circuit is called a parallel diode limiter (A, figure 7-7) because diode CR1 is placed in parallel with the output, and the signal voltage is developed across the diode. When the input signal is positive (B, figure 7-7) the anode is more positive than the cathode and the diode conducts. When the diode conducts it acts as a short circuit across the output terminals and the output voltage is zero (C, figure 7-7). With CR1 conducting, all of the voltage of the input signal is developed across R1. When the input signal drops back to zero or becomes negative, CR1 is reverse biased and no current flows through the circuit, causing the output voltage to follow the input voltage.

(2) Parallel diode clipper. By reversing the diode connections of the parallel diode limiter, the circuit becomes a clipper (A, figure 7-8). A positive input signal (B, figure 7-8) makes the cathode of CR1 more positive than the anode and CR1 is reverse biased. No current flows through R1 and the output voltage equals the input voltage (C, figure 7-8). When the input signal goes negative, CR1 is forward biased and conducts. The signal is developed across R1 while the diode presents a short across the output terminals.

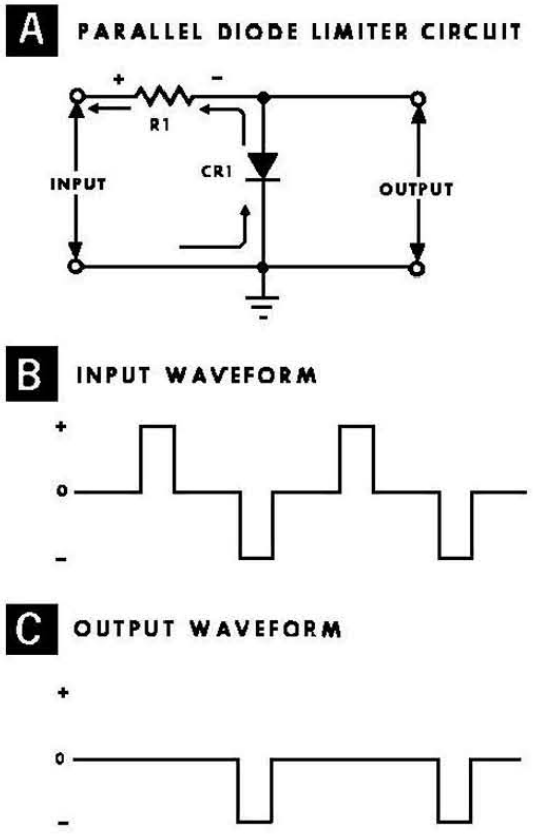


Figure 7-7. Parallel diode limiter.

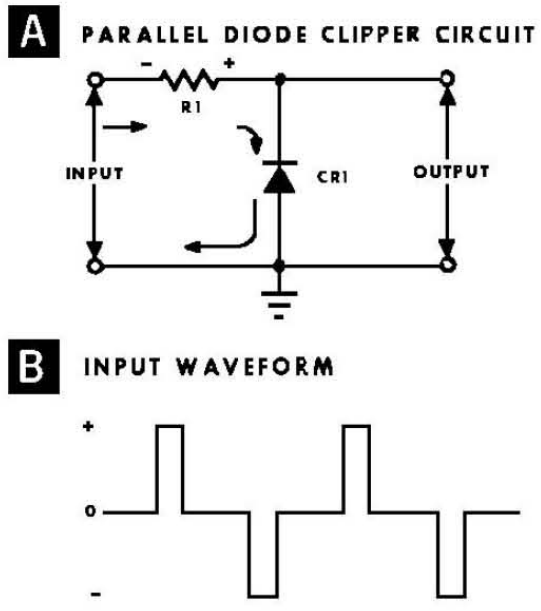


Figure 7-8a. Parallel diode clipper.

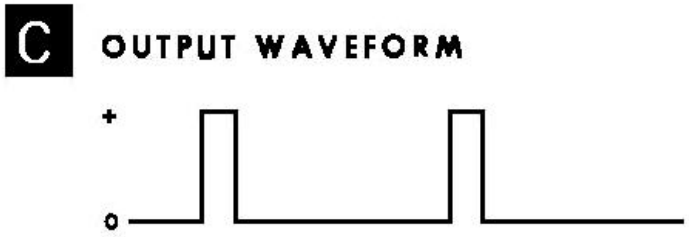


Figure 7-8b. Parallel diode clipper.

j. Biased Parallel Diode Limiter.

(1) Parallel diode limiter with positive bias. In the previously discussed limiter circuits it was possible to limit the signal at the zero reference line. By adding a battery in series with the diode it is possible to change the limiting level of the output signal to any desired value (A, figure 7-9). When the input signal is at zero (B, figure 7-9), diode CR1 is reverse biased. There is zero volts on the anode while the cathode is at +5 volts The diode does not conduct until the input signal exceeds +5 volts. With the diode reverse biased the output signal equals the input signal (C, figure 7-9) When the input signal reaches +5 volts, the diode conducts (effective short circuit) and the output equals the voltage of the bias battery. The output signal remains at +5 volts until the diode is reverse biased by the input signal.

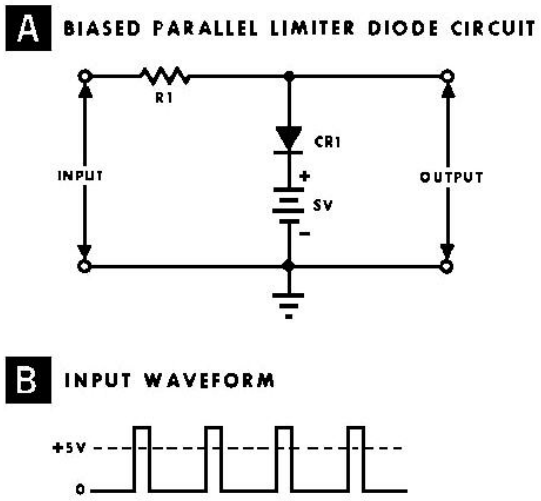


Figure 7-9a. Parallel diode limiter with positive bias.

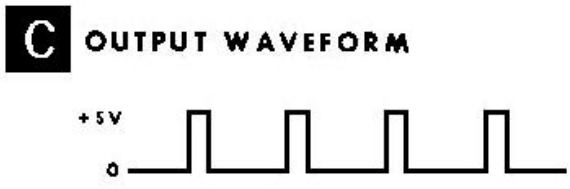


Figure 7-9b. Parallel diode limiter with positive bias.

(2) Parallel diode limiter with negative bias. In this circuit (A, figure 7-10), diode CR1 has -5 volts on its cathode and will conduct only when the anode is more positive than -5 volts. With the input at zero volts (B, figure 7-10), the anode is more positive and CR1 conducts. With CR1 conducting (effective short circuit) the output signal is -5 volts, the value of the bias battery (C, figure 7-10). When the input signal becomes more negative than -5 volts, the diode is reverse biased and is cut off. At this time the output signal equals the value of the input signal. The output waveform will vary from -5 volts to -7.5 volts as CR1 conducts and cuts off.

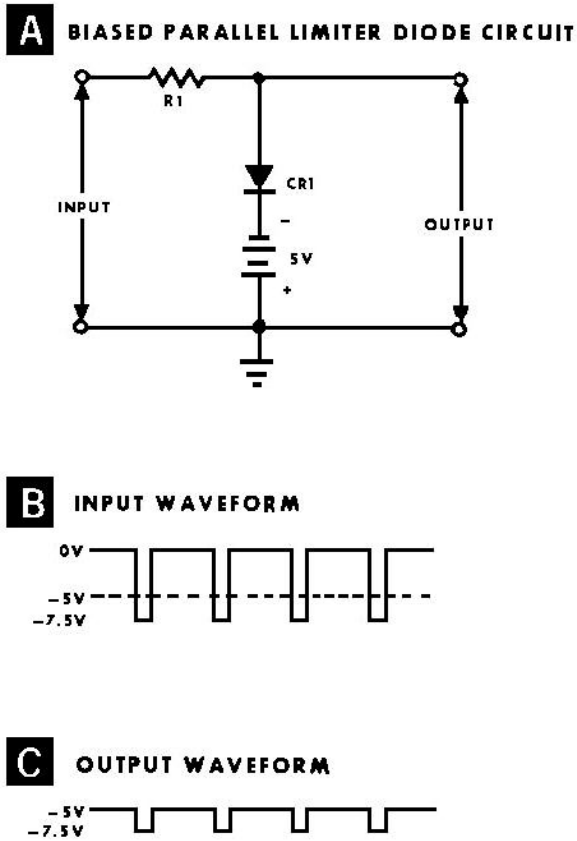


Figure 7-10. Parallel diode limiter with negative bias.

k. Double-Diode Limiter-Clipper. The function of this circuit (A, figure 7-11) is to eliminate unwanted portions of the input signal, above and below a specific level. When the input signal is at zero volts, both diodes CR1 and CR2 are cut off. CR1 has zero volts on its anode and +10 volts on its cathode. CR2 has zero volts on its cathode and -10 volts on its anode. The output signal will then follow the input signal until the input signal exceeds +10 volts (B, figure 7-11). CR1 will conduct, keeping the maximum output volts to +10 volts (C, figure 7-11). When the input drops back below +10 volts, CR1 reverse biased again. When the input voltage is more negative than -10 volts, CR2 will conduct keeping the maximum negative voltage at -10 volts.

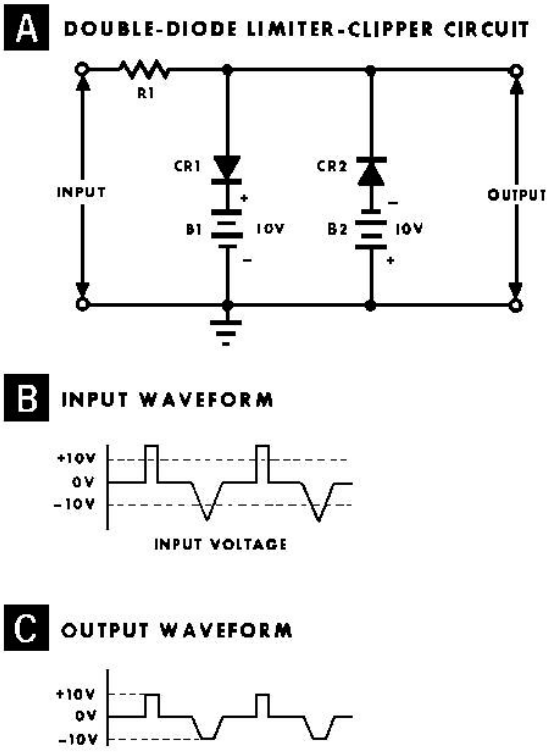


Figure 7-11. Double-diode limiter-clipper.

l. Cutoff And Saturation Clamping. When a transistor is driven to saturation and cutoff, it may introduce undesirable effects in the output waveform. Variations in collector voltage occur when either the temperature-dependent cutoff current or the load changes. This change in collector voltage may cause erratic operation of the succeeding stages. When a transistor is driven to saturation, minority carrier storage delay is introduced. Junction diodes are used to avoid undesirable transistor operation at cutoff or at saturation. Two alternate methods of diode damping that have been devised to avoid saturation of the transistor are collector-emitter clamping and collector-base clamping.

m. Collector-Emitter Clamping. In the circuit shown in figure 7-12, a PNP transistor is used in the CE configuration as a simple switching circuit. Current IB is assumed to be heavy enough to drive the transistor from cutoff to saturation under normal conditions (that is, with clamping diodes CR1 and CR2, and their respective bias batteries Vco and Vcs). In this example, collector bias battery voltage Vc is 12 volts. CR1 and bias battery Vco are used for cutoff clamping. CR2 and its bias battery Vcs are used for saturation clamping. Clamping the upper and lower levels of the output permits the substitution of one transistor for another in this circuit.

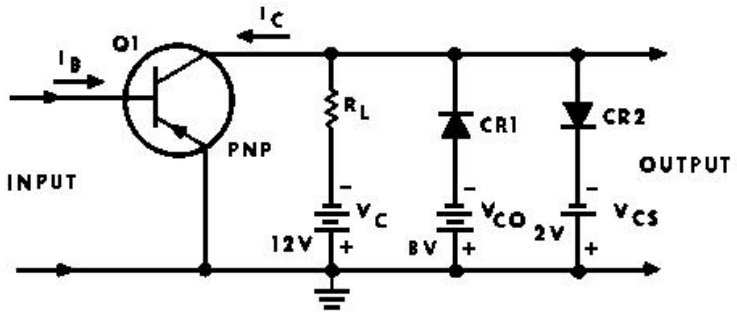


Figure 7-12. Cutoff and saturation clamping.

(1) Cutoff clamping. Assume that input current IB has begun to fall. The collector voltage increases negatively from about 2 volts at this point. As indicated, the bias potential applied to diode CR1 by battery Vco is 8 volts. As the collector voltage increases from 2 volts toward 8 volts, CR1 remains reverse biased (nonconducting).

(a) When the collector voltage reaches 8 volts, CR1 becomes forward biased and begins to conduct. Further decreasing input current IB to zero has no effect on the collector voltage, which remains fixed at 8 volts even though collector current IC decreases (Vco holds Vce at 8 volts).

(b) Current through load resistor RL, however, is maintained about 1 ma and consists of collector current IC and the current through forward biased diode CR1 and battery Vco. The voltage drop across RL is equal to the difference (approximately 4 volts) between the voltages of battery Vc and battery Vco.

(c) Any change in collector current Ic, is compensated for in the amount of current drawn from battery Vc. Equilibrium is maintained and the output voltage is fixed at 8 volts. During this action, CR2 remains reverse biased and is effectively an open circuit.

(2) Saturation clamping. Assume that input current IB is increased to 150 ma. Diode CR1 and its bias battery Vco can be disregarded because they are involved only in establishing the collector cutoff voltage. The collector current increases and the collector voltage changes from -8 to -2 volts.

(a) The collector voltage is clamped at -2 volts by the bias voltage provided by battery Vcs. An additional slight increase in collector current (Ic)--due to an increase in driving current (IB)--further decreases the negative voltage on the collector, and CR2 is forward biased. This effectively places bias battery Vcs between the collector and ground. The current through load resistor R1 is thus fixed to provide the necessary voltage drop so that the collector to ground potential is equal to that of bias battery Vcs.

(b) Although the collector current may increase further because of an increase in base current, the voltage of the collector remains fixed at 2 volts. When the driving current is again reduced to zero, the collector current (Ic) falls rapidly from its maximum value, and the output voltage increases again from -2 to -8 volts.

(3) Combination clamping. The effect of cutoff and saturation clamping is to keep the collector voltage in the range of -2 and -8 volts, thereby preventing cutoff or saturation and the resultant waveform distortion.

n. Collector-Base Saturation Clamping. More efficient switching action is obtained through the use of the single-diode and double-diode collector-to-base clamp.

(1) Single-diode clamping. In the cutoff condition of the transistor, diode CR1 (A, figure 7-13) and the emitter-base diode are reverse-biased by the voltage divider network consisting of resistors R1, R2, and RB in series with collector and base bias batteries Vc and VBB. When batteries Vc and VBB are equal, the sum of the resistances of R1 and R2 is made slightly greater than the resistance of RB. This provides the required initial reverse bias for the emitter-base junction. R1 is very much larger than R2, the ratio of the two resistors being determined by the desired clamping voltage when the transistor is conducting.

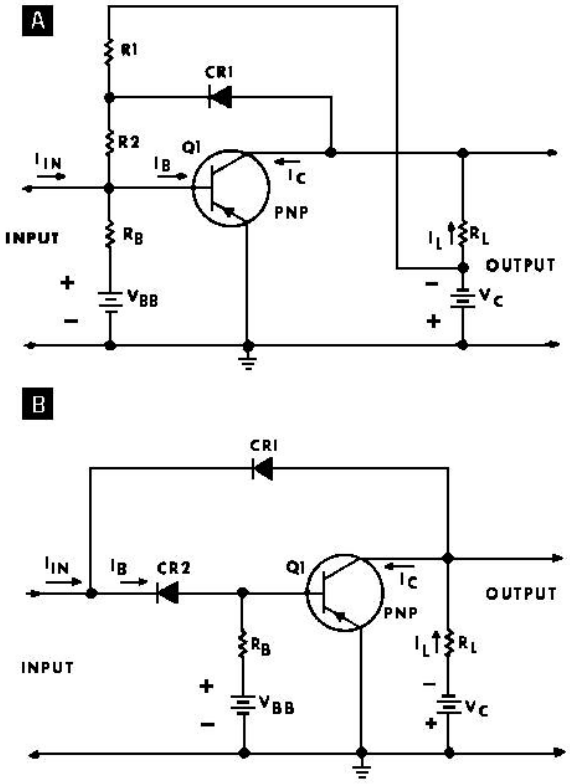


Figure 7-13. Single-diode and double-diode (collector-base) saturation clamping.

(a) Assume that an applied signal (Iin) forward-biases the emitter-base junction, and drives the circuit to saturation. The voltage at the junction of R1 and R2 is negative and effectively fixed near the very low saturation voltage of the transistor used. The collector voltage decreases from its high negative value (Vc) to the value of the voltage at the junction of R1 and R2. During this period, CR1 is nonconducting and base current IB is equal to the input current, Iin. Load current IL is equal to collector current Ic and is the amplified driving current, Iin.

(b) When the collector voltage decreases just below the voltage value at the junction of R1 and R2, CR1 conducts. As input current Iin increases further, base current IB remains essentially constant and the excess current is shunted through R2 and CR 1. Collector current Ic increases by approximately the small value of the excess input current rather than by the amplified input current prior to the clamping effect.

(2) Double-diode clamping. Battery power dissipated by R1 and R2 (A, figure 7-13) is avoided by using double-diode clamping. Diode CR1 (B, figure 7-13) functions as a clamping diode forward-biased diode CR2 is substituted for R2. The emitter-base junction is reverse biased by battery VBB through RB. Collector reverse bias is provided by battery Vc through RL. CR2 remains forward-biased throughout the functioning of the circuit. A negative signal must be applied to the base to drive the transistor into conduction. Generally, a germanium diode, with a low forward voltage drop, is used as the clamping diode (CR1), and a silicon diode, with a slightly higher forward voltage drop, is used as the biasing diode (CR2).

(a) For example, in a typical application, CR1 provides a forward voltage drop of 1 volt and CR2 provides a forward voltage drop of 1.2 volt. This essentially maintains a reverse bias of 0.2 volt between collector and base after clamping action takes place.

(b) Circuit functioning is similar to that of the single-diode clamping circuit. All of input current Iin is applied to the base while CR1 remains reverse biased. This condition exists until load current IL drops the collector voltage just below the voltage value at the junction of CR1 and CR2. The base voltage is more positive than the voltage at this point by the value of the voltage drop across CR2.

(c) CR1 becomes forward biased and shunts the excessive input current to the collector. The smaller voltage drop across CR1 maintains the reverse collector-base bias at the difference between the forward voltage drops across CR1 and CR2.

(d) During the clamped condition, collector current Ic is equal to the sum of load current IL and the shunted portion of input current Iin. This current is small and not an amplified current. Thus, it contributes little to output pulse widening.

2. TRIGGERED CIRCUITS.

a. General. A triggered circuit is one that instantaneously changes its operating state when an external signal is applied to it. Once the applied signal or trigger pulse starts the change in its operating state, the circuit itself completes the action; it is a triggered action. Triggered circuits operate in the astable, monostable, or bistable modes of operation as explained below. Each mode of operation passes through stable regions (cutoff and saturation) and unstable regions (active or transition).

(1) Astable operation. Astable circuits are free-running circuits and trigger pulses are used only for synchronizing purposes. The astable mode of operation results in relaxation-type oscillations and the operating point for this mode is in the active region. The free-running multivibrator is an example of a typical astable circuit.

(2) Monostable operation. The quiescent operating point of the monostable mode is in one of the stable (saturation or cutoff) regions. When the monostable circuit is triggered by an external pulse, its operating point moves from its initial stable region to the other stable region. The time constant of the circuit elements holds the operating point in the new stable region for a period of time and then the operating point moves back to the original state of its own accord. A monostable multivibrator is also referred to as a one-shot, single-shot, or single-swing multivibrator.

(3) Bistable operation. The quiescent operating point of the bistable mode of operation is also in either of the stable regions. When the circuit is triggered by an external pulse, its operating point moves from one stable region to the other. The circuit remains in this second state until a second trigger pulse is applied (the circuit then returns to its original state). Operation of this type of circuit is also referred to as flip-flop action. That is, two trigger pulses are required; one to flip the state of the circuit and the second to flop the circuit back to its original state. The Eccles-Jordan multivibrator is an example of the bistable mode of operation.

b. Monostable Multivibrator. A basic monostable multivibrator is shown in figure 7-14 and its circuit voltage waveforms are in figure 7-15. Bias arrangements hold transistors Q2 in saturation and Q1 at cutoff during the quiescent or steady state period. When a trigger pulse is applied, the multivibrator functions until one full cycle is completed.

(1) Quiescent condition. Battery Vc provides the necessary collector voltage for transistors Q1 and Q2. A negative voltage is applied to the base of Q2 through resistor RF1 causing Q2 to conduct at saturation. When Q2 conducts, its collector voltage is effectively zero. Battery VBB and the voltage developed across resistors RB1 and RF2 cause a positive voltage at the base of Q1. Therefore, Q1 is cutoff and Q2 is conducting. The voltage at the collector of Q1 is at its most negative point and is equal to the value of battery Vc.

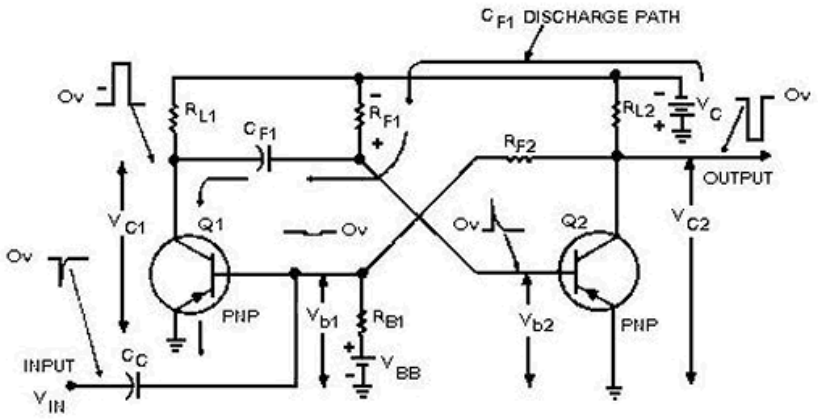


Figure 7-14. Monostable multivibrator.

(2) Circuit operation. To change the states of the transistors, Q1 is started conducting by applying a negative trigger pulse to its base through capacitor Cc. Capacitor CF1 couples any signal changes from the collector of Q1 to the base of Q2.

(a) The negative trigger at the base of Q1 overcomes the reverse bias of battery VBB, forward biases the base to emitter junction, and causes Q1 to start conducting. The high negative voltage of the collector of Q1 starts to decrease (becomes more positive). This positive-going voltage is coupled to the base of Q2, decreasing its base-to-emitter forward bias. Current through Q2 starts to decrease, and the voltage at the collector of Q2 becomes more negative. A portion of this negative voltage is applied to the base of Q1 through resistor RF2, increasing the base-to-emitter forward bias of Q1. In effect, the rapid change in the state of both transistors is caused by driving Q1 into saturation and Q2 into cutoff.

(b) When Q1 started to conduct, capacitor CF1 was fully charged and started to discharge. Its discharge path is through the collector to emitter (low resistance path) of Q1, through battery Vc and resistor RF1, producing the waveform Vb2 in figure 7-15. The initial discharge of CF1 produces the largest positive voltage across RF1 and as the capacitor continues to discharge, the positive voltage decreases.

(c) When the base voltage (Vb2) of Q2 becomes slightly negative, Q2 again conducts. The collector voltage of Q2 increases in the positive direction (waveform Vc2) and is coupled to the base of Q1, driving it into cutoff.

(d) Q1 is again at cutoff, and Q2 is at saturation with its collector voltage almost at zero. This stable condition is maintained until another negative pulse triggers the circuit.

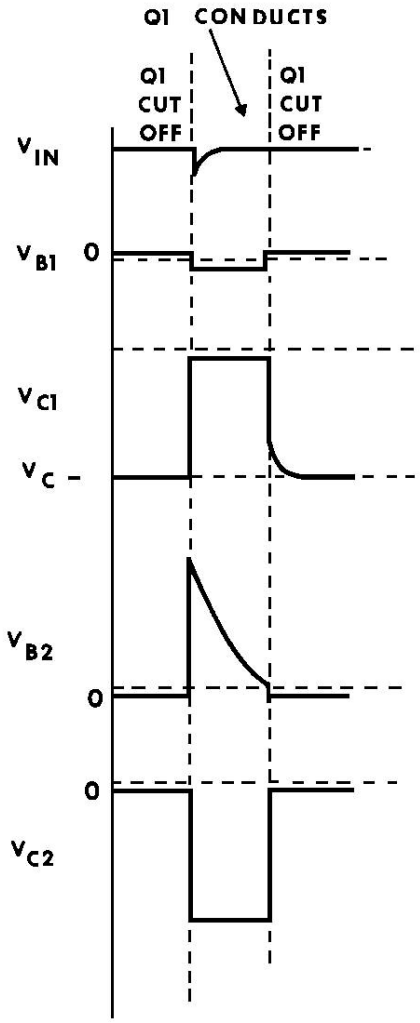


Figure 7-15. Monostable multivibrator waveforms.

(e) The output is taken from the collector of Q2 and is essentially square. The width of the output negative-going pulse is primarily determined by the time it takes CF1 to discharge through RF1 (time constant of CF1 and RF1).

(f) The frequency of this multivibrator is determined by the frequency of the input trigger pulse. If the trigger pulse is applied at a constant frequency, then the output of the multivibrator will be at the same frequency. If the trigger pulse is applied at random intervals, then the output of this multivibrator will be at the same frequency. If the trigger pulse is applied at random intervals, then the output of this multivibrator will be random and contain one output square pulse for every input pulse. Also, the input trigger pulse can be very narrow; the width of the input pulse does not determine the width of the output pulse.

c. Triggered Blocking Oscillator. The major difference between the triggered monostable blocking oscillator in A, figure 7-16, and the astable or free-running blocking oscillator is its bias arrangement. In the free-running mode of operation, the base-emitter junction is forward-biased and the circuit functions as soon as dc power is applied. In the monostable mode of operation, the base-emitter junction is reverse biased and the transistor is held at cutoff. The output (B, figure 7-16) is a single cycle for each input trigger pulse.

(1) Typical blocking oscillator (A, figure 7-16). In the quiescent state, the transistor is held at cutoff by the reverse bias between the base and emitter (supplied by battery VBB). Transformer T1 provides regenerative feedback and couples the output signal to the load. Capacitor CF acts as a dc blocking capacitor and capacitor Cc couples the input signal to the base of the transistor.

(a) When a negative trigger pulse is applied at the input, the transistor begins to conduct. Collector current through transformer winding 3-4 induces a voltage of opposite polarity in winding 1-2. This voltage is coupled through capacitor CF to the base of the transistor as regenerative feedback. This action continues until the transistor is driven into saturation and collector current ceases to increase.

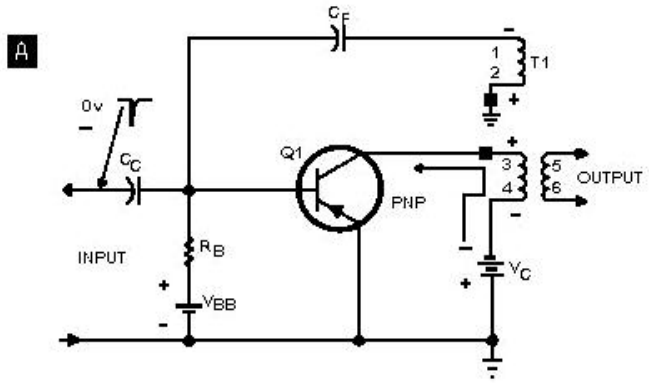


Figure 7-16a. Triggered blocking oscillator.

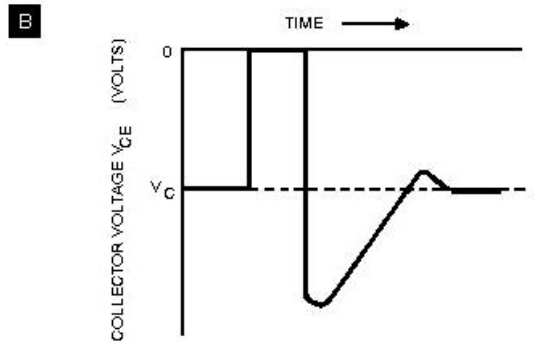


Figure 7-16b. Triggered blocking oscillator.

(b) At saturation when the collector current becomes constant, no feedback voltage is induced in transformer T1 and the reverse bias from battery VBB cuts off the transistor. The collector current continues for a very short while because of minority carrier storage.

(c) When the collector current stops, the collapsing field around transformer winding 1-2 induces a voltage in winding 3-4 that exceeds battery voltage Vc (B, figure 7-16). In some instances, this backswing voltage may exceed the collector breakdown of the transistor. Driving the transistor into the saturation region introduces the undesired effect of minority carrier storage.

(2) Blocking oscillator with clamping diodes. A triggered blocking oscillator can be modified with clamping diodes (figure 7-17) to prevent voltage breakdown and reduce the effects of minority carrier storage. The circuit operates the same as the one described above except for the following differences.

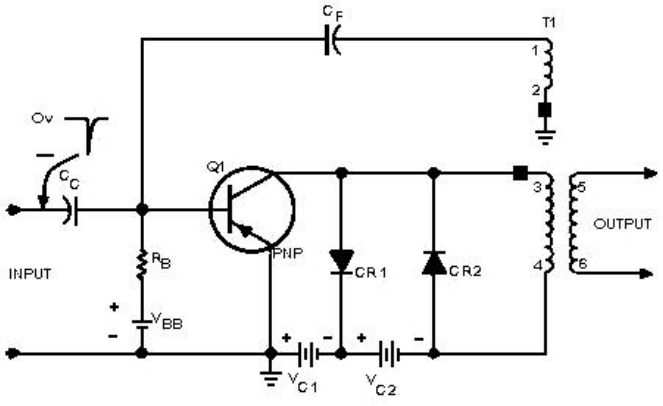


Figure 7-17. Triggered blocking oscillator with clamping

(a) The base-to-emitter junction is reverse biased by battery VBB. The combined voltage of batteries VC1 and VC2 provide collector voltage. During the quiescent condition CR1 is reverse biased and CR2 has no bias (the same voltage appears at the cathode and anode). When a negative trigger pulse is applied to the base of Q1, the transistor is driven from cutoff to conduction. Collector current increases rapidly as a result of regeneration. The collector voltage, swings in the positive direction until it equals the voltage of battery Vc1.

(b) As the collector voltage of the transistor decreases (becomes less negative), CR2 becomes reverse biased. The effect of CR2 may be neglected as long as it remains reverse biased (open circuit). The initial reverse bias voltage that had been applied to CR1 decreases until the collector voltage equals the voltage of battery Vc1. A further increase in collector current causes a further decrease in the collector voltage. This action results in forward biasing CR1, which will now conduct and maintain a constant voltage, equal to the value of battery Vc1, at the collector. When CR1 conducts it acts as a short circuit around the 3-4 winding of T1 and prevents the transformer from going into saturation. When the magnetic field begins to collapse, the collector voltage becomes more negative (B, figure 7-16); the bias voltage across CR1 reverts to its nonconducting state value when the value of Vc1 is exceeded. The collector voltage increases negatively until it reaches the value of Vc1 and Vc2. Any attempt by the induced voltage to further increase the negative voltage at the collector is overcome by the conduction of CR2. The charge in transformer winding 3-4 is then discharged through this diode, and thus prevents excessive voltage between the collector and the emitter. The negative going voltage does not drop below voltage Vc, and the voltage swing below Vc is eliminated by CR2.

d. Bistable Multivibrator Circuits. A bistable circuit is initially at rest in either one of its stable states. When triggered by an input pulse, the circuit switches to its second stable state where it remains until triggered by another pulse.

(1) Conventional bistable multivibrator. A basic Eccles-Jordan bistable multivibrator is shown in figure 7-18. This circuit differs from the astable multivibrator primarily in the base-emitter arrangement. In the stable state, either transistor may be in the on state while the other is off. The states of the transistors are switched when a trigger pulse is applied.

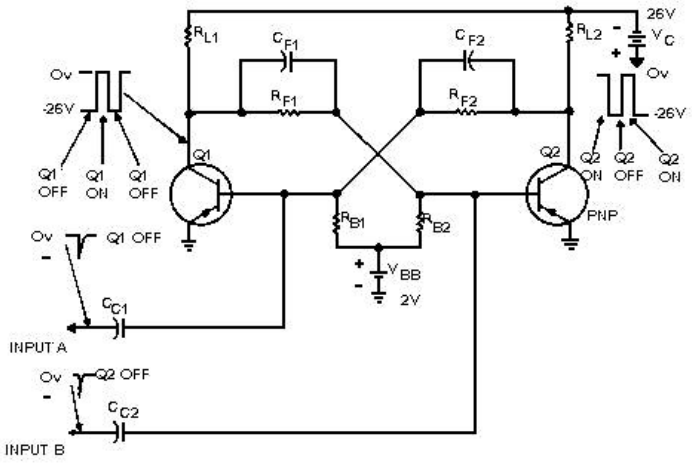


Figure 7-18. Conventional bistable multivibrator.

(a) Cutoff and saturation conditions. When power is applied to the circuit, one transistor will turn on and the other will cut off. Each transistor is held in its particular state by the condition of the other. When a transistor is cut off, its collector current is effectively zero, and its collector voltage is equal to the value of collector battery Vc. In the figure, assume that transistor Q1 is cutoff and transistor Q2 is conducting at saturation. The collector voltage of Q1 is approximately -26v. Notice the voltage divider consisting of resistors RF1 and RB2; at this time one end of RF1 is at -26v and one end of RB2 is at +2v (A, figure 7-19). The total voltage across the divider is 28 volts. Assume that RF1 has a 21 volt drop across it and RB2 has a 7-volt drop. The junctions of these two resistors provide base bias for Q2. The effective bias on the base of Q2 is -5 volts with respect to ground (voltage drop across RB2 less voltage at VBB). With the base of Q2 at -5 volts, Q2 will conduct at the saturation level. When Q2 conducts, collector current through resistor RL2 causes the voltage of the collector (Q2) to drop to zero volts. There is another voltage divider from the collector of Q2 to battery VBB made up of resistors RB1 and RF2 (B, figure 7-19). One end of this divider is at zero volts and the other end is +2 volts; the total voltage across the divider is 2 volts. Assume that RF2 drops 1.5 volt and RB1 drops 0.5 volt. The junction between the two resistors provides bias for the base of Q1. This voltage (+1.5 volt) will reverse bias the base of Q1 and cause it to cut off.

(b) Circuit operation (figure 7-18) The conditions described above establish one of the two stable states of the multivibrator. Two separate negative inputs are shown. A trigger pulse at input A will change the state of the circuit. Once the state of the circuit is changed, an input of the same polarity at input B, or an input of opposite polarity at input A, will again trigger the circuit.

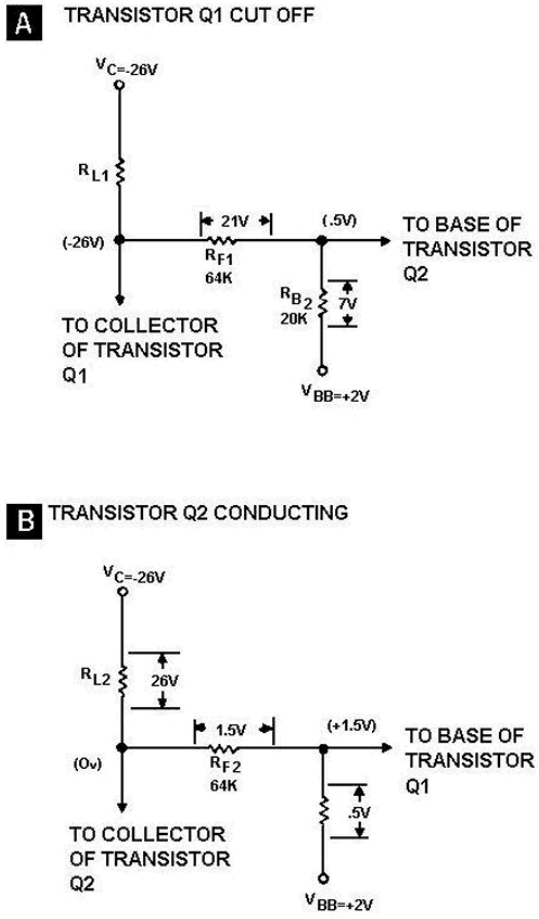


Figure 7-19. Voltage divider networks showing Q1 cut off and Q2 saturated.

1. Assume that Q1 is cut off and Q2 is conducting. When a negative trigger pulse is applied at input A, Q1 begins to conduct. The rise in the collector current of Q1 causes its collector voltage to go to zero volts. This change in collector voltage is coupled to the base of Q2, through capacitor CF1; it reduces the forward bias of Q2 and conduction in Q2 begins to decrease. The collector current of Q2 decreases, and its collector voltage changes from zero to a negative value (approaching the value of battery voltage Vc). This change in voltage is coupled to the base of Q1, through capacitor CF2, making its base more negative; conduction in Q1 increases. This regenerative feedback continues until Q1 is at saturation and Q2 is cut off. After both transistors have changed states, the actions and effects of the two voltage dividers reverse. Resistors RF1 and RB2 will now reverse bias the base of Q2 to +1.5 volt, keeping Q2 cut off. Resistors RF2 and RB1 will forward bias the base of Q1 to -5 volts, keeping Q1 conducting at saturation. To change the circuit back to the first stable state simply apply a negative trigger pulse at input B. This will start Q2 conducting again, and in turn, will cause Q1 to return to its cutoff condition.

2. Essentially, the time constants of capacitor CF1 and resistor RF1 and of CF2 determine the switching time (from conduction to cutoff) of Q1 and Q2, respectively. In addition, the capacitors quickly couple the changing voltages to the bases of the transistors to insure rapid switching action. The output, taken between collector and ground, is a unit step voltage when one trigger is applied. A square-wave output can be obtained by continuous triggering.

(2) Direct coupled bistable multivibrator. A direct-coupled bistable multivibrator is shown in A, figure 7-20. It is also called a binary counter or a count-by-two circuit in computing and counting applications. In the circuit shown, transistors Q1 and Q4 are not considered part of the bistable multivibrator; they provide input control of the conducting state of the circuit. The collector-to-emitter voltage for the off transistor is the low base-emitter voltage of the on transistor. Operation of the circuit is as follows:

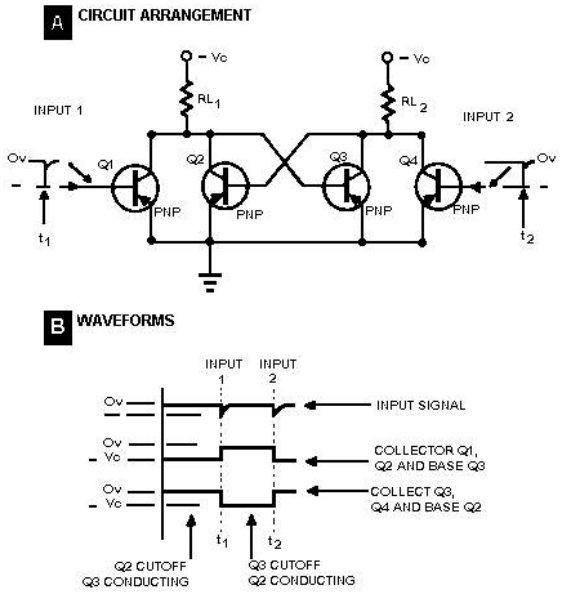


Figure 7-20. Direct-coupled bistable multivibtator.

(a) Assume that transistor Q2 is cut off and transistor Q3 is conducting. The collector voltage of the off Q2 is the same voltage (-Vc) that is applied to the base of Q3. The circuit is triggered by effectively grounding the collector of the off Q2. At time T1 (B, figure 7-20), a negative input pulse is applied to the base of Q1, causing it to conduct. The collector voltage of Q1 rises toward ground potential (equal to the voltage developed across resistor RL1). The base voltage of Q3 will approach ground potential causing Q3 to cut off (base voltage of Q3 is the same as collector voltage of Q1). When Q3 cuts off, its collector voltage approaches the negative value of the applied voltage. The negative collector voltage of Q3 is applied direct to the base of Q2, causing Q2 to conduct. The voltages applied between collectors and bases of Q2 and Q3 result in the rapid change of state of the circuit. The circuit reaches a state of equilibrium; Q2 is now conducting and Q3 is cut off.

(b) At time T2 a negative input pulse is applied to the base of transistor Q4, causing it to conduct. The conduction of Q4 through resistor RL2 causes the collector of Q3 and base of Q2 to approach ground potential. Transistor Q2 will cut off and its collector voltage applied to the base of Q3 causes Q3 to conduct. Transistor Q2 is now cut off and Q3 is conducting which was the state of both transistors before input pulses were applied to Q1 and Q4. The circuit will remain stable until another input pulse is applied to the base of Q1. The negative pulse at time T1 may be called a set pulse, and the input pulse at time T2 may be considered a reset pulse that brings the circuit back to its original state.

e. Trigger Pulse Steering. Several methods are available for applying the triggering pulse on pulses to a bistable multivibrator circuit. The method selected is determined by the polarity and magnitude of the trigger pulse. The trigger pulse is usually either a pulse of extremely short duration or a unit step voltage.

(1) Triggering methods. The trigger pulse may be applied to the base or to the collector of either transistor in a bistable multivibrator circuit. Triggering may be accomplished in one of four following ways. The four methods described are for PNP transistors; all polarities must be reversed for NPN transistors.

(a) A negative trigger pulse is applied to the base of the off transistor (figure 7-18). This pulse drives the transistor out of cutoff into conduction.

(b) A positive trigger pulse may be applied to the base of the on transistor to cut it off.

(c) A negative trigger pulse may be applied to the collector of the on transistor (figures 7-18 and 7-20). This pulse is also applied to the base of the off transistor, causing it to conduct.

(d) A positive trigger pulse may be applied to the collector of the off transistor (figures 7-18 and 7-20). This pulse is also applied to the base of the on transistor, causing it to cut off.

(e) In all cases the trigger pulses must be of sufficient amplitude to reverse the stable states of the transistors.

(2) Diode steering, single input. In certain applications, it is desirable to trigger a bistable multivibrator (figure 7-21) on and off repeatedly with input pulses of the same polarity. If the same pulse were applied simultaneously to both the off and on transistors, the circuit would not respond quickly enough and switching time would be delayed. Using pulse steering diodes, the input pulse is quickly directed to the proper transistor.

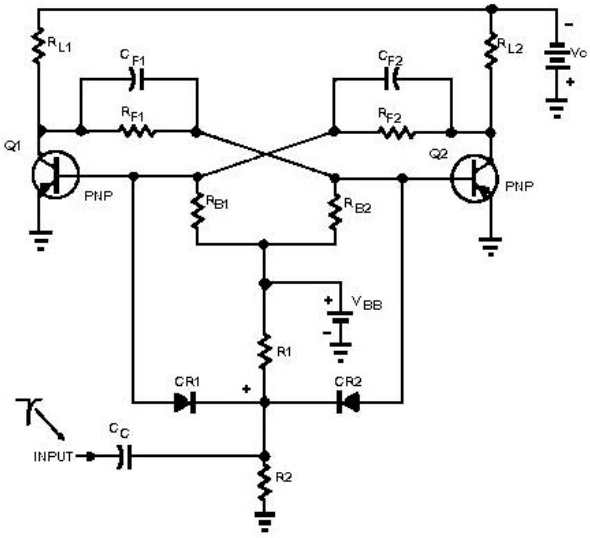


Figure 7-21. Bistable multivibrator with negative-pulse

(a) Negative pulse steering (A, figure 7-22). Resistors R1 and R2 form a voltage divider so that the cathodes of both diodes are at a positive potential. As shown in the figure, diode CR1 is in its nonconducting state because of the applied reverse bias. Diode CR2 is conducting due to forward bias (its anode is more positive than the small positive voltage applied to the cathode). When a negative trigger pulse is applied to coupling capacitor Cc, reverse biased diode CR1 prevents the pulse from being applied to the base of the on transistor. Forward biased diode CR2 allows the negative trigger pulse to be applied to the base of the off transistor, causing it to conduct. The switching function of the multivibrator takes place and the on transistor is now off while the off transistor is now on. Diode CR1 is now forward biased and CR2 is reverse biased. The next negative trigger pulse will be applied to the off transistor through forward biased diode CR1 and will cause the circuit to go back to its original state.

(b) Positive pulse steering (B, figure 7-22). In the circuit, the diodes are reversed and a negative source voltage is used. Resistors R1 and R2 form a voltage divider and apply a negative voltage to the anodes of diodes CR1 and CR2. Diode CR1 is forward biased while diode CR2 is reverse biased. A positive trigger pulse is, therefore, applied through CR1 to the base of the on transistor, driving it to cutoff. The reverse bias on CR2 prevents the trigger pulse from being applied to the base of the off transistor. Once the circuit switches state, the bias conditions of the diodes are reversed and a second positive pulse is directed through forward biased diode CR2 to the base of the on transistor. If a negative trigger pulse is applied to this circuit, it will only increase the reverse bias of the reverse biased diode and have no effect on the operation of the circuit.

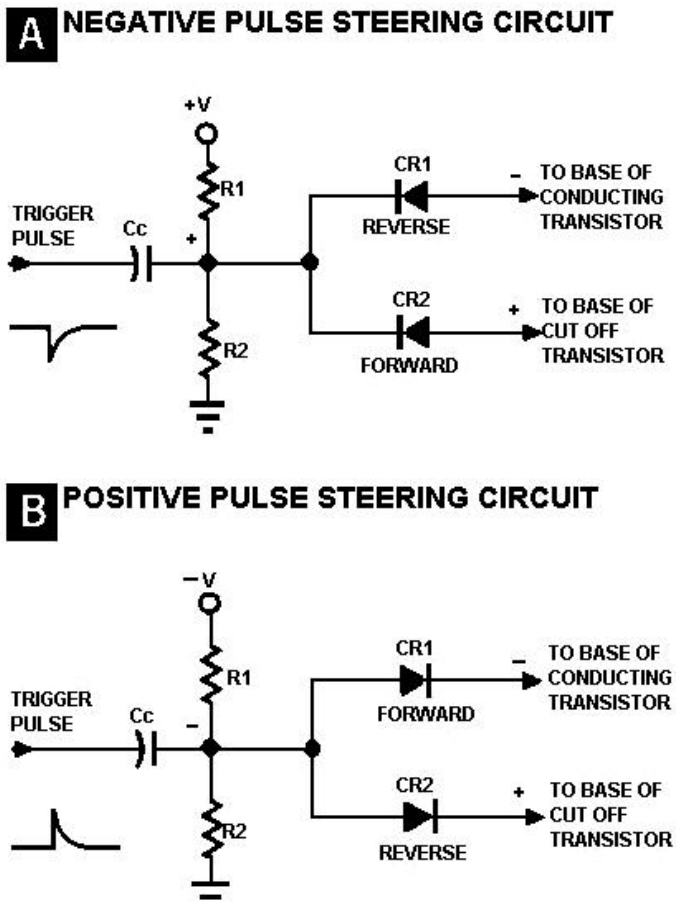


Figure 7-22. Pulse steering diodes.

(3) Transistor pulse steering. The amount of time for the change of state of a bistable multivibrator may be decreased by using a symmetrical transistor for pulse steering (figure 7-23). A symmetrical transistor (Q3) is one in which the emitter-base and collector-base junctions are identical. If the bias on each junction is reversed the transistor continues to function except that the direction of current is reversed. When the collector-base junction is forward biased and the emitter-base junction is reverse biased, the collector functions as the emitter and the emitter functions as the collector. This reversal of current permits trigger pulse steering.

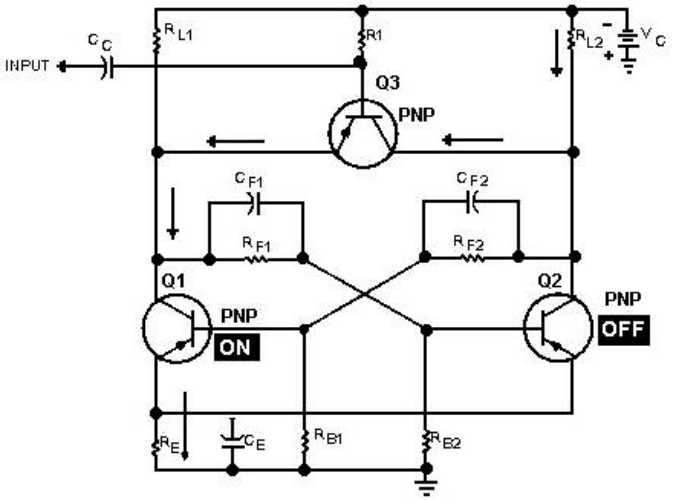


Figure 7-23. Bistable multivibrator using a transistor for

(a) When transistor Q1 operates near saturation and Q2 is cutoff, the collector voltage of Q1 is near ground potential and the collector voltage of Q2 equals the source voltage (Vc). With this condition and with no input signal applied, Q3 is conducting. Current (direction of arrows) is from battery Vc, through resistor RL2 and to the collector of Q3. Current leaves the emitter (Q3) and goes to the collector of Q1, then from the emitter (Q1) through resistor RE and back to ground.

(b) A negative trigger pulse applied at the input increases the conduction in transistor Q3. The increased collector current from battery Vc through load resistor RL2 causes the collector voltage of Q2 to become more positive (less negative). This increased positive voltage is applied to the base of Q1 through the network of CF2 and RF2, and drives Q1 into cutoff. When circuit equilibrium is reached, Q1 is at cutoff and Q2 is at saturation. Because of this, a reversal of transistor bias is established across the junctions of Q3. Current at this time is from the negative battery terminal, through load resistor RL1, through the emitter of Q3 to the collector of Q2. Current leaves the emitter of Q2 and goes to ground through emitter resistor RE. If another negative trigger pulse is applied to Q3, then the circuit reverts back to its initial condition.

f. Squaring Circuit (Schmitt Trigger). A Schmitt trigger is another multivibrator that must have a pulse applied at the input to obtain an output pulse. The Schmitt trigger differs from the conventional bistable multivibrator in the method of coupling between its two stages. The output of this circuit is a square wave no matter what the shape of the input pulse (figure 7-24). Thus, the Schmitt trigger circuit converts distorted input square wave signals to undistorted square wave output signals.

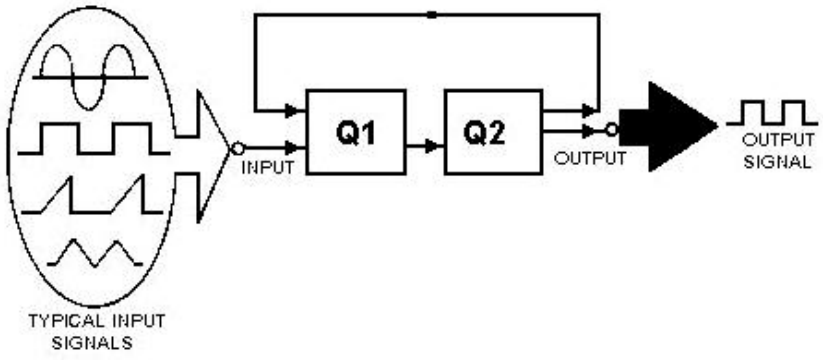


Figure 7-24. Examples of input signals to the Schmitt trigger.

(1) Circuit operation. Resistors R1, R3, and R4 form a voltage divider between ground (the most negative point) and supply voltage Vc (figure 7-25). Current through resistor R4 develops a positive voltage at the base of transistor Q2. During the quiescent period, this positive base voltage causes Q2 to conduct. Resistor R5 is a common emitter resistor for both transistors, and current through either transistor develops a voltage across R5. The voltage developed across R4 is greater than the voltage applied to the emitter of Q2 by R5. Therefore, Q2 is forward biased. Transistor Q1 is reverse biased by the voltage developed across R5 because the emitter of Q1 is positive compared to its base. Thus, when you turn on the Schmitt trigger circuit, Q1 is driven to cutoff and Q2 is driven to saturation.

(2) Input trigger pulse. To cause the circuit to change state, transistor Q1 must be driven into conduction and Q2 must be cut off. Any positive trigger signal applied to the base of Q1, large enough to overcome the emitter bias, will change the operation of both transistors. Assume that an ac sine wave is used as the trigger.

(a) When the positive half cycle increases enough to overcome its emitter bias, Q1 starts to conduct. As Q1 conducts toward saturation, its collector current increases. When the collector current through resistor R1 increases, the voltage developed across R1 also increases. Remembering that R1 is part of a voltage divider with resistors R3 and R4, if more voltage is developed across R1, then less voltage is available across the other two resistors. As the voltage across R4 decreases, the base-to-emitter bias on Q2 decreases until the transistor is reverse biased and cuts off. The circuit remains in this condition as long as the input signal voltage on the base of Q1 is greater than the bias on its emitter (figure 7-26). When the signal voltage on the base of Q1 falls off enough to make the base less positive than the emitter, the circuit switches back to its original state.

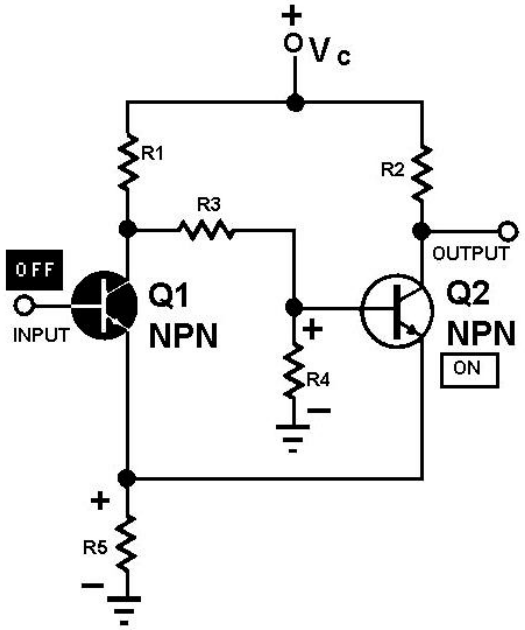


Figure 7-25. Quiescent condition of Schmitt trigger.

(b) When the signal voltage on the base of Q1 approaches the voltage of the emitter, collector current through Q1 starts to decrease. There is less current through R1 which, in turn, develops less voltage. If R1 develops less voltage, then more voltage is available across R3 and R4. The increased voltage across R4 will again forward bias Q2 and cause it to conduct. This continues until Q1 is cut off and Q2 conducts to saturation. The output waveform of the circuit resembles a square wave.

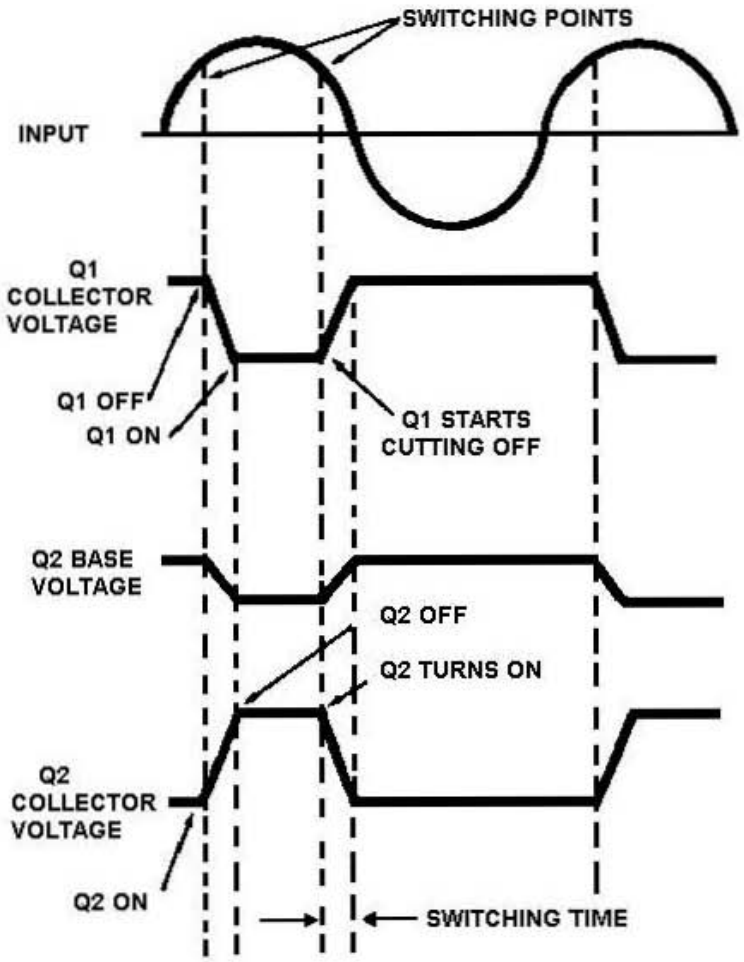


Figure 7-26. Schmitt trigger waveforms.

MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS

EXERCISES FOR LESSON 7

1. In the ideal pulse and switching circuit the current

   A. will lead the voltage by 90 degrees.
   B. undergoes instantaneous changes in step with voltage changes.
   C. lags the voltage by 90 degrees.
   D. is of little importance since all transistors are voltage handling devices.

2. What does a transistor act as during a large-signal nonlinear operation?

   A. Inverter
   B. Attenuator
   C. Filter
   D. Overdriven amplifier

3. What is the operating condition of the transistor in figure 7-2 (A) when S1 is placed in the ON position?

   A. Cutoff
   B. Reversed bias
   C. Conducting due to forward biasing of the emitter-base junction
   D. Shorted

4. Which region(s) of transistor operation acts similar to a normal amplifier?

   A. Saturation
   B. Active and cutoff
   C. Active
   D. Cutoff

5. What does the common emitter configuration act as when used in pulse and switching circuits?

   A. Series switch
   B. Class A amplifier
   C. Shunt switch
   D. Peaking circuit

6. In figure 7-3 the pulse is the length of time that the pulse remains at, or near, its maximum value. What percentage of its maximum amplitude is this pulse measured?

   A. 97
   B. 95
   C. 90
   D. 85

7. What type of circuit would you use if you wanted the output voltage to be held constant at both higher and lower levels?

   A. Limiter-clipper
   B. Limiter
   C. Clipper
   D. Clamper

8. In figures 7-5 and 7-6, what is the condition of diode CR1 when acting as a series clipper?

   A. Conducting when a negative pulse is present at the input
   B. Cathode is more positive than the anode
   C. Reverse biased with a positive signal input
   D. Conducting when a positive pulse present at the input

9. At what input voltage in figure 7-9 does the diode CR1 conduct?

   A. 0v
   B. Exceeds +5v
   C. From 0v to +5v
   D. Never conducts

10. Which of the following statements is true concerning figure 7-7?

   A. A parallel diode clipper is illustrated in figure 7-7
   B. In figure 7-7 the signal voltage is developed across resistor R1
   C. When the input signal goes positive CR1 will not conduct in figure 7-7
   D. In figure 7-7 the signal voltage is developed across diode CR1

11. When the input signal of figure 7-11 is zero volts, what diode(s) conducts?

   A. CR1
   B. CR2
   C. CR1 and CR2
   D. Neither diode conducts

12. What is introduced in the operation of a transistor when it is driven to saturation?

   A. A ringing effect
   B. The transistor develops a short
   C. Minority carrier storage delay is introduced
   D. The transistor will overheat and break down

13. What component(s) is (are) used for saturation clamping in figure 7-12?

A. RL and VC
B. Vcs and CR2
C. CR2
D. CR1 and Vco

14. In figure 7-13 the single-diode collector base saturation is clamping when bias batteries Vc and VBB are equal. What must the relation be between the bias resistors?

A. RB resistance is slightly less than the resistance of R2 and R1
B. R1 and R2 resistance is slightly less than resistance RB
C. RL is one-half the total of resistances R1, R2, and RB
D. RB resistance is twice that of resistance R2

15. What component on figure 7-13 in the double-diode configuration is substituted for R2 in the single-diode configuration?

A. RB
B. CR1
C. CR2
D. RL

16. A free-running circuit that uses a trigger only for synchronizing purposes is called

A. a monostable circuit.
B. a bistable circuit.
C. a one-shot circuit.
D. an astable circuit.

17. On figure 7-14, what is the initial condition of transistors Q1 and Q2 during the steady state period?

A. Both transistors are conducting
B. Q1 is in saturation and Q2 is cutoff
C. Q2 is in saturation and Q1 is in cutoff
D. Both transistors are cutoff

18. On figure 7-14, what determines the width of the monostable multivibrator?

A. Width of the input pulse
B. Discharge time of CF1
C. Size of resistor RB1
D. Size of resistor RL2

19. What is the operating condition of Q1 at the highest point of the positive pulse shown in figure 7-16, part B?

A. Saturated
B. Cutoff
C. At a high conduction rate
D. At a low conduction rate

20. When CR1 on figure 7-17 conducts, it acts as a short circuit

A. across Q1.
B. across Vc2.
C. around winding 3 and 4 of T1.
D. CR2.

21. What voltage would be monitored at the junction of RL2, CF2, and RF2 of figure 7-18 when Q1 is conducting?

A. -5 volts
B. 0 volts
C. +26 volts
D. -26 volts

22. Using figure 7-20 with Q2 conducting and Q3 cut off, what voltages will be monitored at the base of Q3 and the collector of Q4?

A. Base of Q3 is -Vc, and collector of Q4 is -Vc
B. Base of Q3 is 0v, and collector of Q4 is-Vc
C. Base of Q3 is -Vc, and collector of Q4 is 0v
D. Base of Q3 is 0v, and collector of Q4 is 0v

23. In order to trigger a bistable multivibrator circuit, the trigger must be

A. a positive pulse applied to the collector of the off NPN transistor.
B. a negative pulse applied to the collector of the off PNP transistor.
C. a negative pulse applied to the on PNP transistor base to cut it off.
D. a negative pulse applied to the base of the PNP off transistor.

24. Q1 on figure 7-21 is conducting and Q2 cutoff when CR2 opens. What is the condition of the multivibrator when the next trigger pulse is applied to the circuit?

A. Q1 conducts and Q2 cutoff
B. Q1 and Q2 cutoff
C. Q1 and Q2 conducts
D. Q1 cutoff and Q2 conducts

25. What is the key for successful operation of the transistor pulse steering of a bistable multivibrator on figure 7-23?

A. All transistors must be symmetrical
B. Trigger pulses must be alternately positive and negative
C. Use a symmetrical PNP transistor for pulse steering
D. Design of circuit allows both Q1 and Q2 to conduct at the same time

LESSON 8. MODULATION AND DEMODULATION

MMS Subcourse Number 701..... Transistors and Semiconductors

Lesson Objective..... To provide the student with a general knowledge of transistorized modulation and demodulation circuits.

Credit Hours..... Two

TEXT

1. MODULATION.

a. General. The three basic types of modulation are amplitude modulation, frequency modulation, and phase modulation. Since frequency and phase modulation are very similar, only amplitude modulation (AM) and frequency modulation (FM) will be discussed in this lesson. Amplitude modulation can be accomplished by applying a carrier signal to an amplifier and varying the amplifier bias at the modulating rate. Frequency modulation can be accomplished by varying the frequency of an oscillator at the modulating rate. There are various methods of modulating an oscillator to obtain either AM or FM modulation.

b. Amplitude Modulation.

(1) Amplitude-modulated amplifier. The waveform analysis of an amplitude-modulated amplifier is shown in A, figure 8-1. The carrier signal is applied to the amplifier; and, the bias, which varies the gain of the amplifier, is varied by the modulating signal input. The output of the amplifier is an amplitude-modulated carrier. As the carrier signal passes through the amplifier, the gain of the amplifier is increased or decreased. When the amplifier gain is increased, the output is increased and when the amplifier gain is decreased, the output is decreased. Thus, the amplitude of the carrier signal is varied at the modulating rate.

(2) Amplitude-modulated oscillator. The waveform analysis of an amplitude-modulator oscillator is shown in B, figure 8-1. The carrier signal is generated by the oscillator and the modulating signal varies the bias. Changing the bias of the oscillator changes the gain and the operating point of the transistor. Changing the bias provides amplitude changes to the output frequency of the oscillator.

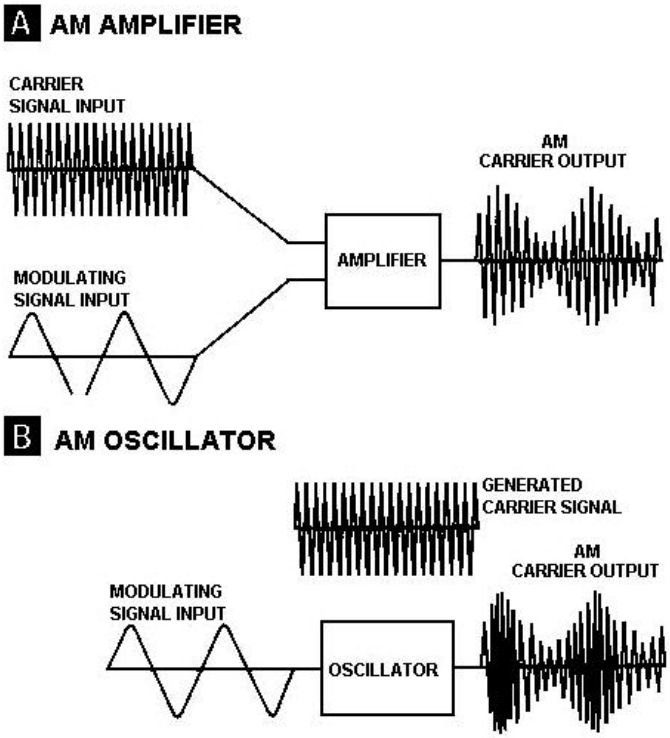


Figure 8-1. Amplitude modulation of an amplifier and an oscillator.

c. Methods Of Amplitude Modulating An Amplifier.

(1) General. An amplifier may be AM modulated by injecting a modulating signal into either its base, emitter, or collector (figure 8-2). Each method will vary the gain of the transistor.

(a) Transformer T1A, T1B, or T1C provides base, emitter, or collector injection, respectively. Any change in bias changes the gain of the transistor, which results in amplitude variations in the output signal. The carrier signal, coupled through transformer T1, is applied to the base circuit of amplifier Q1. Capacitor C1 and the primary of transformer T2 form a parallel resonant circuit for the amplified carrier signal.

(b) The signal on the collector is increased in amplitude when the bias is increased, and decreased in amplitude when the bias is decreased. The result is an amplitude-modulated carrier coupled through transformer T2 to the following stage. If the strength of the RF carrier signal is greater than the emitter-base bias, when the amplifier is modulated by base injection or emitter injection the modulated output will be distorted. Under these conditions, the RF carrier signal must determine the emitter-base bias instead of the modulating signal. Thus, the strength of the RF carrier must always be less than the emitter-base bias when an amplifier is modulated with base injection or emitter injection.

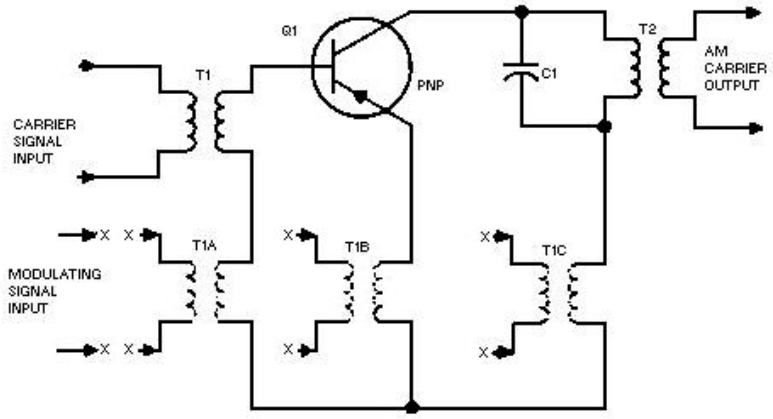


Figure 8-2. Methods of injecting amplitude modulating signal into amplifier circuit.

(2) Amplitude-modulated amplifier (base injection). The carrier signal input is coupled through transformer T1 to the base circuit of amplifier Q1 (figure 8-3). The modulating signal, coupled through capacitor C1, is developed across resistor R1.

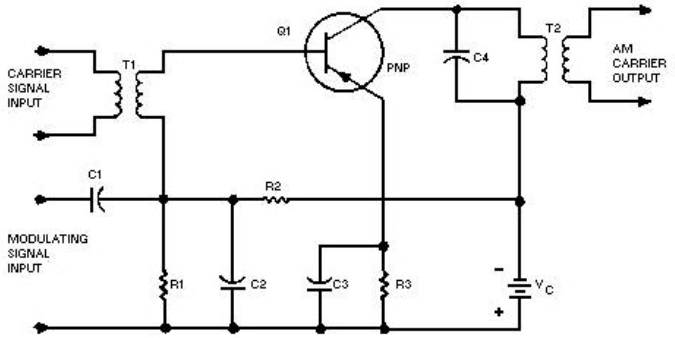


Figure 8-3. Amplitude-modulated amplifier with base injection.

(a) The bias developed across resistor R1 is increased when the modulating signal increases and decreases when the modulating signal decreases. Thus, the base-emitter bias is increased and decreased as the modulating signal increases and decreases.

(b) Since the base-emitter bias is changing at the modulating rate, the collector current and the gain are changing at the modulating rate. As the gain increases, the amplitude of the carrier signal increases; and, as the gain decreases, the amplitude of the carrier signal decreases. The amplitude changing carrier signal (modulated carrier signal), present in the parallel resonant circuit of capacitor C4 and the primary of transformer T2, is coupled through the transformer to the output.

(3) Amplitude-modulated amplifier (emitter injection). Emitter injection is very similar to base injection; both methods vary the emitter-base bias. The carrier signal input is coupled through transformer T1 to the emitter circuit of amplifier Q1 (figure 8-4). The modulating signal, coupled through capacitor C1, is developed across swamping resistor R3.

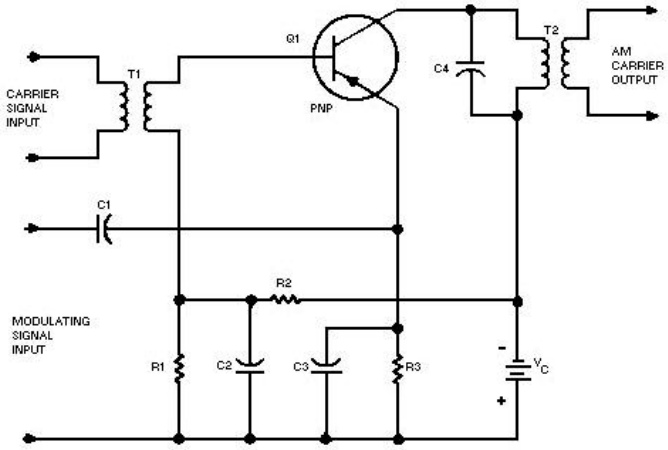


Figure 8-4. Amplitude-modulated amplifier with emitter injection.

(a) When the voltage drop (modulating signal voltage) across resistor R3 aids the voltage drop across series resistor R1, the emitter-base bias increases. When the voltage drop (modulating signal voltage) across resistor R3 opposes the voltage drop across series resistor R1, the emitter-base bias decreases. When the emitter-base bias increases, the gain of amplifier Q1 increases and when the bias decreases, the gain decreases.

(b) As the gain increases, the amplitude of the carrier signal on the collector increases; and, when the gain decreases, the amplitude of the carrier signal decreases. The modulated carrier signal, present in the parallel resonant circuit of capacitor C4 and the primary of transformer T2, is coupled through the transformer to the output.

(4) Amplitude-modulated amplifier (collector injection). In this circuit, the emitter-base voltage is held constant and the voltage between the emitter and the collector is varied at the modulating rate. The carrier signal is applied through transformer T1 to the base circuit (figure 8-5). Amplifier Q1 amplifies the carrier signal.

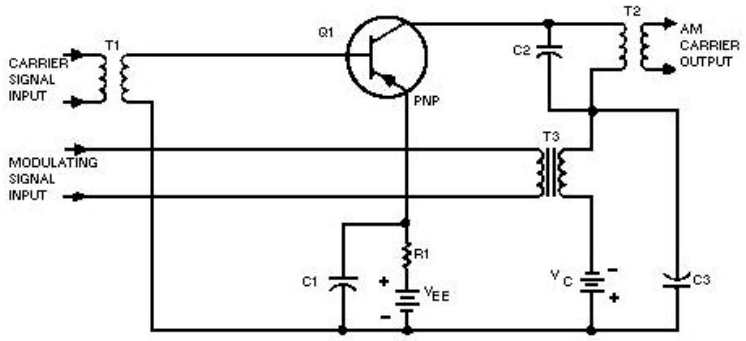


Figure 8-5. Amplitude-modulated amplifier with collector injection.

(a) The carrier signal is developed across the resonant circuit consisting of capacitor C2 and the primary of transformer T2. The modulating signal is applied through transformer T3 to the collector circuit. The modulating voltage across the secondary of transformer T3 is in series with collector battery voltage Vc.

(b) When the modulating voltage is in series with and aids the battery voltage Vc, it increases the emitter-collector voltage. When the modulating voltage is in series with and opposes battery voltage Vc, it decreases the emitter-collector voltage. As the emitter-collector voltage increases, the gain of amplifier Q1 increases; and, as the emitter-collector voltage decreases, the gain decreases. Thus, when the gain of amplifier Q1 increases, the amplitude of the carrier signal increases; and when the gain decreases, the amplitude decreases.

d. Methods Of Amplitude Modulating An Oscillator.

(1) General. An oscillator may be modulated by injecting a modulating signal into the base, the emitter, or the collector (figure 8-6). Each method will change the gain and the operating point of the transistor. This results in amplitude changes and frequency changes in the output of the oscillator. Transformer T1A, T1B, or T1C provides base, emitter, or collector injection, respectively. Amplifier Q1 provides the amplification required for oscillation and winding 3-4 of transformer T2 provides the required feedback. Capacitor C1 and winding 1-2 of T2 provide the required resonant circuit. Winding 5-6 of T2 couples the output signal to the following stage.

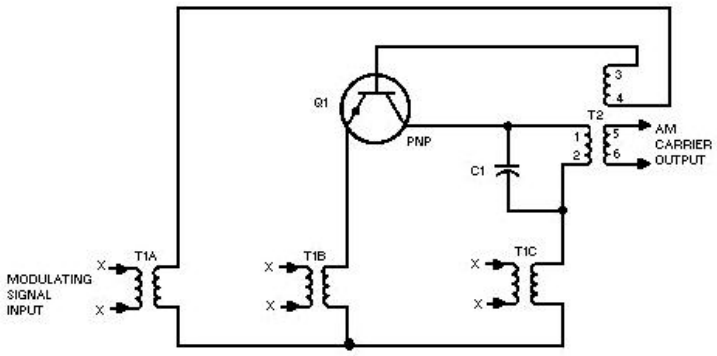


Figure 8-6. Methods of injecting amplitude-modulating signal into oscillator circuit.

(2) Amplitude-modulated oscillator (base injection). The modulating signal voltage from microphone M1 is developed across variable resistor R1 (figure 8-7). The amount of modulating signal voltage is determined by the setting of R1 and is applied to the base circuit. Inductor L1 and capacitor C1, series resonant at the carrier frequency, act as an open circuit for the modulating signal voltage and bypass the carrier signal around R1.

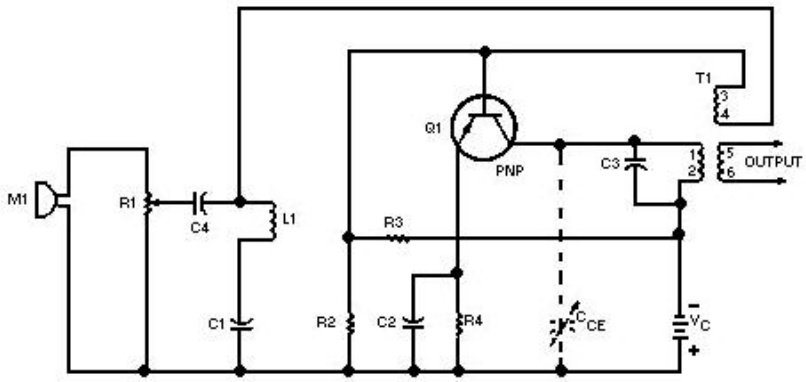


Figure 8-7. Amplitude-modulated oscillator with base injection.

(a) An aiding modulating signal voltage increases the emitter-base bias and an opposing modulating signal voltage decreases the emitter-base bias. An increase in the bias increases the gain of transistor Q1 and a decrease in the bias decreases its gain. An increase in the gain of Q1 increases its amplification of the generated signal, and a decrease in the gain decreases the amplification. The generated signal is therefore amplitude-modulated at the modulating rate.

(b) An increase in gain of Q1 also decreases its collector voltage, which increases capacitance CCE; and, a decrease in the gain increases the collector voltage, which decreases CCE. Capacitance CCE is in parallel with the resonant circuit consisting of capacitor C3 and winding 1-2 of T1. Increasing capacitance CCE decreases the resonant frequency of the resonant circuit, and decreasing capacitance CCE increases the resonant frequency. Since the frequency of oscillation is determined by this resonant circuit, the output frequency of the oscillator is changing at the modulating rate. Thus, the output signal of the amplitude-modulated oscillator is amplitude and frequency modulated at the modulating rate.

e. Establish Frequency Modulation.

(1) General. The input and output waveforms of a frequency-modulated oscillator are shown in figure 8-8. In an FM transmitter, modulation is accomplished at the oscillator stage. A transistor oscillator can be frequency modulated by varying the oscillator gain at the modulating rate. The same amplitude-modulated oscillator used in an AM transmitter can be used in an FM transmitter. The unwanted amplitude changes can be removed by a limiter stage before the carrier signal is increased in frequency and strength.

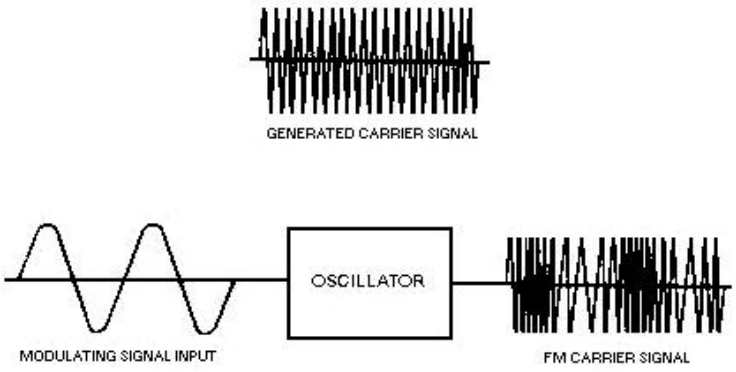


Figure 8-8. Block diagram of frequency-modulated oscillator.

(2) Frequency-modulated oscillator. A typical frequency-modulated oscillator stage is shown in figure 8-9. In this application, frequency modulation is accomplished by reactance modulation. The modulating signal, coupled through transformer T2, varies the emitter-base bias of reactance modulator Q2.

(a) Since the bias is increasing and decreasing at the modulating rate, the collector voltage also increases and decreases at the modulating rate. As the collector voltage increases, output capacitance CCE decreases; and, as the collector voltage decreases, CCE increases. When output capacitance CCE decreases, the resonant frequency of the oscillator (Q1) tank circuit (capacitor C1 and winding 1-3 of transformer T1) increases. When CCE increases, the resonant frequency of the oscillator tank circuit decreases.

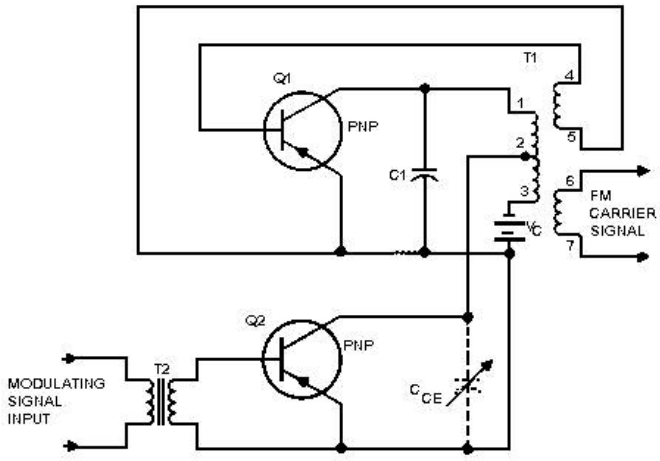


Figure 8-9. Oscillator circuit, frequency modulated by a reactance modulator.

(b) The resonant frequency of the oscillator tank circuit is therefore increasing and decreasing at the modulating rate. Thus, the frequency of the signal generated by the oscillator is increasing and decreasing at the modulating rate. The output of the oscillator is, therefore, a frequency-modulated carrier signal.

2. DEMODULATION.

a. General. The three basic types of demodulation or detection are CW detection, AM detection, and FM detection.

(1) CW detection. CW detection is accomplished by combining the carrier signal with the output of an oscillator to produce an audio signal. The oscillator stage used for this purpose in a superheterodyne receiver is called a beat frequency oscillator (bfo). The bfo frequency is adjusted to differ from the intermediate frequency of the receiver by a low audio frequency.

(2) AM detection. The waveforms and the AM detector are shown in A, figure 8-10. The amplitude-modulated carrier signal is applied to the AM detector. The AM detector rectifies and filters the amplitude variations of the carrier signal. The output of the AM detector is an audio signal.

(3) FM detection. FM detection may be accomplished by using a discriminator or a slope detector as an AM detector. The waveforms of FM detection are shown in B, figure 8-10. The frequency-modulated carrier signal is applied to the FM detector which rectifies and filters the frequency variations of the carrier signal. The output of the FM detector is an audio signal.

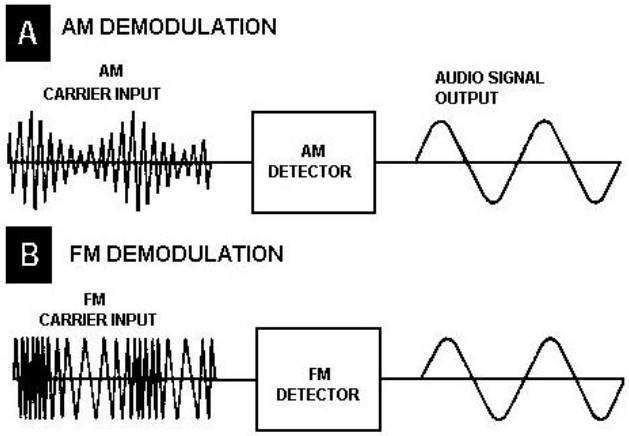


Figure 8-10. Input and output waveforms for AM and FM detection.

b. AM Demodulation With A Transistorized Detector.

(1) Common emitter circuit. A common emitter detector is shown in figure 8-11. The signal applied to the base emitter circuit (biased for nonlinear operation) is rectified by the diode portion (base-emitter) of detector Q1. Resistor R1 acts as the diode load resistor and capacitor C2 filters the IF voltage changes. The input circuit acts as a voltage output diode detector. The base-emitter bias (audio voltage) developed across resistor R1 causes the collector current to vary at the audio rate. The amplified audio signal developed across resistor R4 is coupled through capacitor C5 to the following stage.

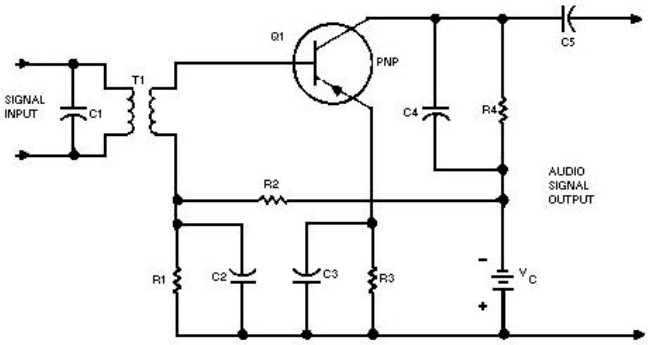


Figure 8-11. Common emitter detector circuit.

(2) Common base circuit. A common base detector is shown in figure 8-12. Detection takes place in the emitter-base circuit of transistor detector Q1; and, amplification takes place in the collector-base circuit. When the signal is positive at the emitter, there is current through the emitter-base circuit. Capacitor C2 charges on the positive alternation and discharges through resistor R1 on the negative alternation. The long time constant of C2 and R1 does not allow C2 to completely discharge during the negative alternation. Then, the next positive alternation again recharges C2. The result is that the peaks of the positive alternation are filtered by C2. The bias between the emitter and the base is, therefore, a dc voltage with an audio voltage component. Thus, the amplitude changes of the signal are detected in the emitter-base circuit of detector Q1. Since the bias of the emitter-base circuit is changing at the audio rate, the collector current also changes at the audio rate. The detected audio signal is coupled to the output through transformer T2.

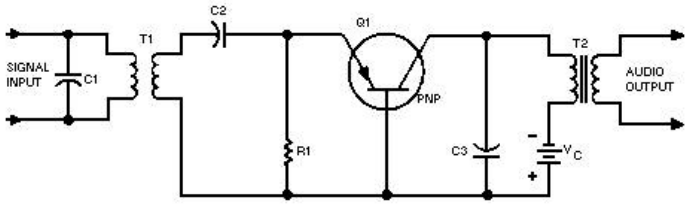


Figure 8-12. Common-base detector circuit.

c. FM Demodulation Using A Discriminator Circuit. A discriminator in an FM receiver performs the same function as a detector in an AM receiver. Figure 8-13 shows a transistorized version of an amplifier stage and a discriminator. Amplifier Q1 amplifies the signal applied to the discriminator. Capacitor C2 and the primary of transformer T1 form a parallel resonant circuit for the signal; T1 also couples the signal to the discriminator. Capacitor C3 couples the signal to the secondary of T1 for phase shift comparison. The signal, coupled across capacitor C3, is developed across coil L1. Capacitor C4 and the secondary of transformer T1 form a resonant circuit. The top half of transformer T1 secondary, diode CR1, coil L1, load resistor R2, and filter capacitor C5 form one-half of a comparison network. The bottom half of the transformer T1 secondary, diode CR2, coil L1, load resistor R3, and filter capacitor C6 form the second half of a comparison network. The audio output is coupled through capacitor C7 to the primary of transformer T2. The audio signal, coupled through transformer T2, is applied to the following stage.

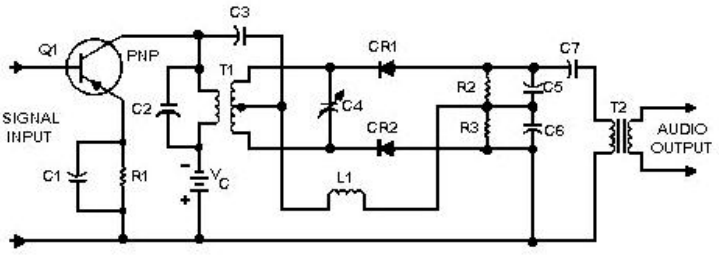


Figure 8-13. Amplifier and discriminator stage.

d. FM Demodulation Using A Slope Detector.

(1) A slope detector converts the frequency changes of a carrier signal into amplitude changes. The amplitude changes can then be detected by an AM diode detector or an AM transistor detector. The input and output waveforms of a slope detector and an AM diode detector are shown in figure 8-14. The input signal with frequency deviations is applied to slope detector Q1. The output of slope detector Q1, with amplitude and frequency deviations, is applied to diode detector CR1. The resultant output is an audio signal which is equivalent to the frequency deviations of the input signal.

(2) The FM input signal is coupled through transformer T1 to the base circuit of Q1. This signal is developed across resonant circuit consisting of coil L1 and capacitor C2. This resonant circuit is tuned slightly higher than the FM carrier.

(a) When the FM carrier frequency deviation (containing the intelligence) approaches the resonant frequency of L1-C2, a large amount of signal voltage is developed. On the other hand, when the frequency deviation goes lower than the resonant frequency, a smaller amount of signal voltage is developed.

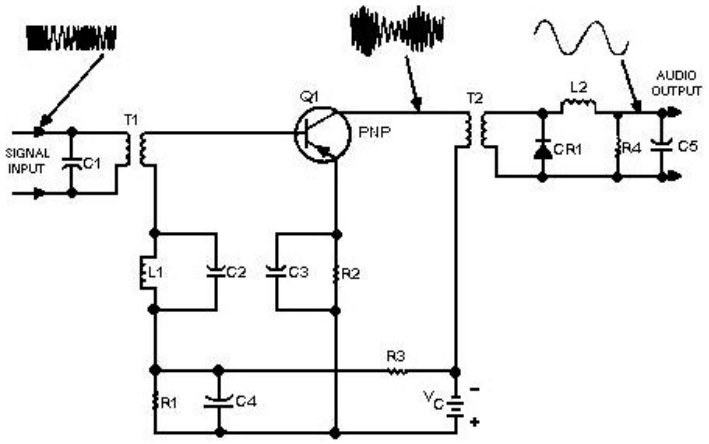


Figure 8-14. Slope detector and diode detector.

(b) The voltage thus developed across the resonant circuit (L1-C2) is in series with the emitter-base bias voltage developed across R1. The result is that the emitter-base bias voltage varies at a rate determined by the deviation of the FM carrier.

(c) Since the bias of slope detector Q1 changes at the frequency deviation rate, its gain also changes at the frequency deviation rate. Thus, the output of the slope detector is a signal that is changing in amplitude and frequency.

(d) The output of Q1 is applied to diode detector CR1. The detected output signal is an audio voltage developed across resistor R4.

MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS

EXERCISES FOR LESSON 8

1. What are the basic types of modulation?

   A. Frequency and amplitude
   B. Frequency and phase
   C. Amplitude and phase
   D. Amplitude, phase, and frequency

2. What is the primary difference between the amplitude-modulated amplifier and the amplitude-modulated oscillator configurations?

   A. In the AM amplifier the carrier signal is generated within the amplifier
   B. In the AM oscillator the output is half the amplitude of the AM amplifier
   C. The carrier signal is injected in the AM amplifier, but is generated within the AM oscillator
   D. The AM oscillator converts to a modulated signal at a higher speed than the AM amplifier

3. If the RF carrier strength is greater than the modulating signal input into an AM amplifier circuit, using base or emitter injection, what would result?

   A. Output would be attenuated
   B. Output would be distorted
   C. Amplifier would go into saturation
   D. Amplifier would cut off

4. What components on figure 8-7 comprise the tank circuit?

   A. R1, C4, L1, and C1
   B. C2 and R4
   C. CCE, C3, and T1 windings 3-4
   D. T1 windings 1-2 and C3

5. Using figure 8-9 what happens to the resonant frequency when transistor output capacitance decreases?

   A. Remains the same
   B. Increases
   C. Decreases
   D. Amplitude of the carrier signal decreases

6. What are the basic types of detection?

   A. FM and PM
   B. CW and QW
   C. CW, FM, and AM
   D. AM, PM, and QW

7. What is the oscillator stage of a CW detection circuit called?

   A. Beat frequency oscillator
   B. Free-running oscillator
   D. High-frequency oscillator
   C. Carrier oscillator

8. What component(s) on figure 8-11 rectifies the signal input?

   A. C4 and R4
   B. R1 and R2
   C. Base-emitter of Q1
   D. C3

9. What function on figure 8-13 is performed by C2 and the primary of T1?

   A. Grounds all low frequencies
   B. Forms a parallel resonant circuit
   C. Grounds all high frequencies
   D. Forms a series resonant circuit

10. Using figure 8-14 what function is performed by the slope detector?

   A. Converts the audio signal into a carrier signal
   B. Changes the operating level of Q1 into a high gain amplifier
   C. Develops the signal input into frequency deviations
   D. Converts the frequency changes of the carrier signal into amplitude changes

11. Using figure 8-14 what will happen if the FM carrier frequency, approaching the resonant frequency of L1-C2, is lower than the resonant frequency?

A. A large amount of signal voltage is developed
B. A small amount of signal voltage is developed
C. The signal is grounded
D. The signal will be distorted

12. What is the function performed by CCE on figure 8-7?

A. Changes the resonant frequency of the resonant circuit
B. Changes the operating frequency of the modulator circuit
C. Maintains constant output frequency for amplitude modulation
D. Maintains constant output frequency for frequency modulation

13. What best describes the bias between the emitter and the base on figure 8-12?

A. An ac voltage
B. A dc voltage
C. A dc voltage with an audio voltage component
D. An ac voltage with an audio voltage component

14. What duplicates the same function as a discriminator in a FM receiver?

A. A detector in an AM receiver
B. A damper in an AM receiver
C. The modulating rate in an AM oscillator
D. Filter in an AM modulator

15. Which type of modulation varies the frequency of an oscillator at the modulating rate?

A. AM
B. PM
C. CW
D. FM

LESSON 9. SPECIAL PURPOSE SEMICONDUCTOR DEVICES

MMS Subcourse Number 701..... Transistors and Semiconductors

Lesson Objective..... To introduce the student to the various applications and uses of semiconductors and integrated circuit modules.

Credit Hours..... Three

TEXT

1. GENERAL.

a. Introduction.

(1) Since the development of the transistor, continuous research in the field of semiconductors has provided many additional semiconductor devices. Some of these devices, now considered as innovations in military and commercial equipment, may become as commonplace as the junction transistor is today.

(2) The junction transistor was really the second phase in transistor development; the point-contact transistor was discovered before it. But the junction transistor proved much more versatile than the point-contact and rapidly came into widespread use. That's why the preceding lessons of this subcourse are about the theory and application of junction transistor circuits. In this lesson, applications of the point-contact transistor, other semiconductor devices, and integrated circuits will be discussed.

b. Point-Contact Transistor.

(1) The point-contact transistor consists of a single piece of P-type or N-type material. The base contact forms a large area (low resistance) connection, but the emitter and the collector contacts form small area (high resistance) connections.

(2) Although the point-contact transistor can be made of N-type or a P-type material, small P-type or N-type layers, respectively, are used under the contact points (figure 9-1). The P or N layers under the contact points are formed during the manufacturing process. For biasing polarities, the N-type point-contact transistor (A, figure 9-1) may be considered similar to a PNP junction transistor; and, the P-type point-contact transistor (B, figure 9-1), may be considered similar to an NPN junction transistor. The emitter is biased in the forward direction with respect to the base and the collector is biased in the reverse direction with respect to the base.

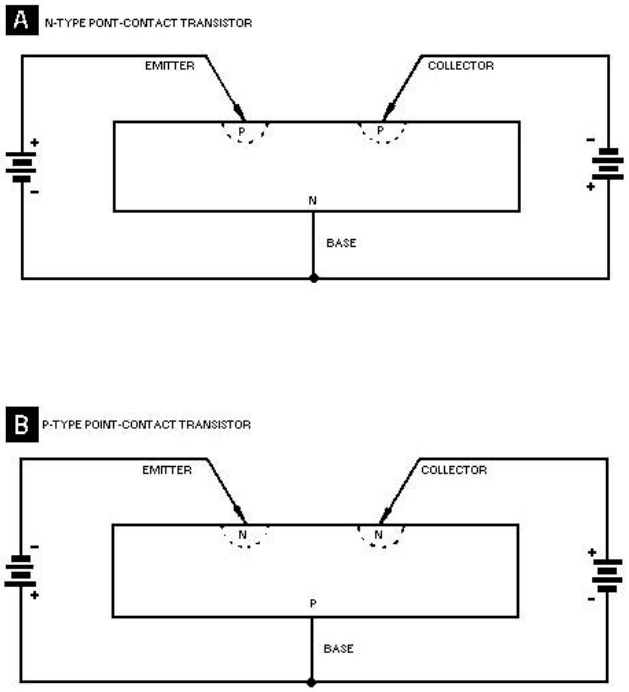


Figure 9-1. Bias for N-type and P-type point-contact transistor.

(3) The positive potential of the emitter (figure 9-2) causes holes in the emitter to move across the narrow N region of the base between the contact points. The negative collector potential attracts the holes from the emitter where they combine with electrons entering the collector from the power source. Relatively few holes combine with electrons in the N region between the contact points to produce a small value of base current due to the bias voltage.

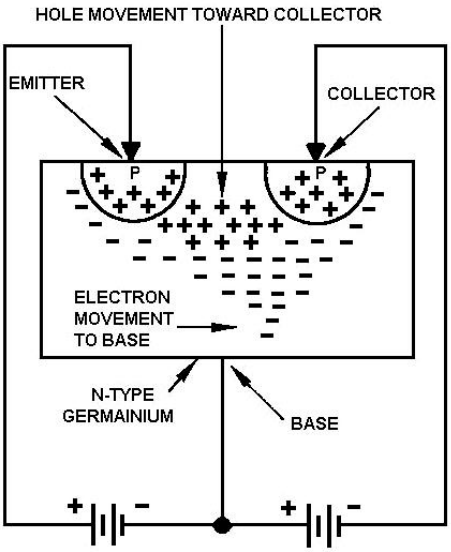


Figure 9-2. Current flow through N-type point-contact transistor.

(4) Two metal "cat whiskers" are used as the contacts of the point-contact transistor. The contacts are shaped to provide a spring-like pressure on the crystal surface. The shaping between the contacts may be as little as 2/1000 inch, and the diameter of the contact 5/1000 inch.

(5) The spacing between the contact points affects the frequency response of point-contact transistors. The spacing affects the transit time required for holes to flow from the emitter to the collector; reducing the space between the contact points increases the frequency response.

(6) Because of their physical construction, point-contact transistors are not suitable for handling power in excess of one watt. The limitation results from the fact that the emitter and collector electrodes are very fine wires pressed against a semiconductor wafer. High current or heavy surges damage the transistor because the contact points overheat.

c. Photosensitive Semiconductors.

(1) General. In a photosensitive semiconductor, light energy causes the movement of the carriers. To control the movement of carriers in a photosensitive semiconductor, the light energy must be concentrated on a sensitive area of the semiconductor. When the concentrated beam of light strikes the sensitive area, the current through the semiconductor increases. As the intensity of the light energy is varied, the current through the semiconductor varies. An increase or decrease in the intensity of the light causes a proportional increase or decrease in the current through the semiconductor. Because of this characteristic, photosensitive semiconductors (point-contact and junction types) are used in various circuits for detection, translation, switching, etc.

(2) Point-contact type. To operate the point-contact photosensitive semiconductor shown in A, figure 9-3, energy from a light source is concentrated into a beam by the lens and strikes the sensitive area. Note that the semiconductor material is hollow-ground on one side so that the light energy may be concentrated on the sensitive area. As the intensity of the light source is increased and decreased, current through the load resistor changes proportionally. Thus, the light energy is converted into electrical energy and an output signal is developed across the load resistor.

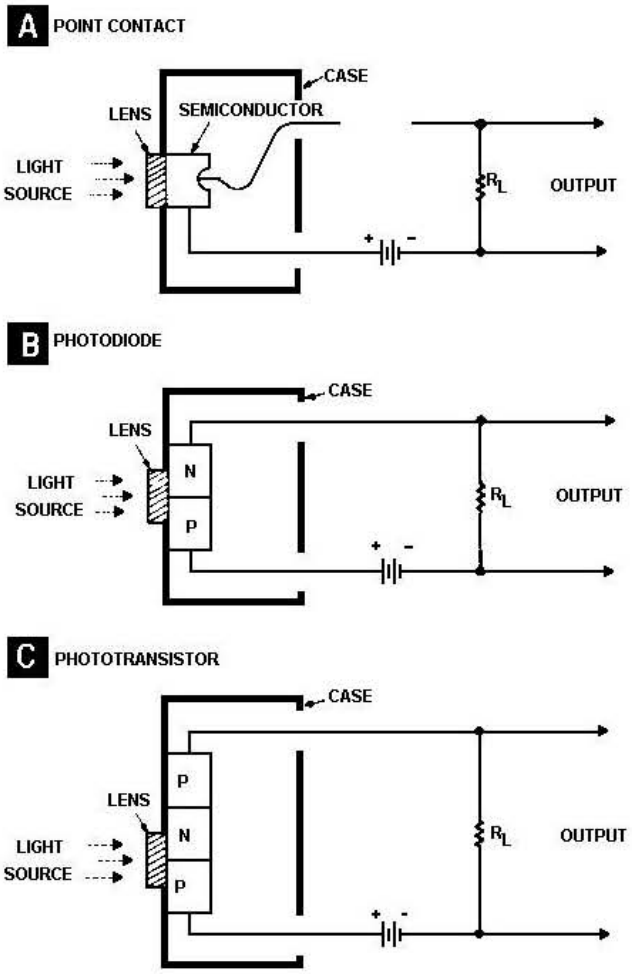


Figure 9-3. Photosensitive semiconductors.

(3) Junction type.

(a) Single (photodiode). A single-junction photosensitive semiconductor circuit is shown in B, figure 9-3. The operation of this circuit is identical with that described above except for the photosensitive semiconductor. The sensitive area is located at the PN junction and may be located in either of the semiconductor materials.

(b) Double (phototransistor). A double-junction photosensitive semiconductor circuit is shown in C, figure 9-3. It works the same as the single-junction type except that it may be compared to a junction transistor amplifier. The light energy, which strikes the first PN junction, is equivalent to a signal applied to the emitter-base junction of a transistor amplifier. Current amplification takes place in the second PN junction, which is equivalent to the collector-base circuit of a transistor amplifier.

d. Tetrode Transistor.

(1) The tetrode transistor is basically either an NPN or a PNP transistor with a fourth terminal (which is called base 2). The fourth terminal is connected to the base region on the side opposite the normal base connector (figure 9-4). In the NPN circuit described below, base 2 is biased negative with respect to the normal transistor base terminal (base 1). The voltage applied to base 2 is considerably higher than the bias applied to base 1.

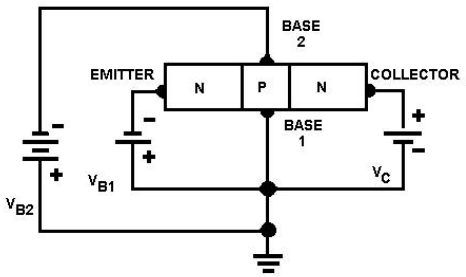


Figure 9-4. Tetrode bias.

(2) The purpose of the increased bias on base 2 is to change the current through the transistor (figure 9-5). The 6-volt bias is applied between base 1 and base 2 making base 2 six volts more negative than base 1. The 6-volt bias is applied uniformly across the length of the base region, starting with -6 volts at the top to 0 volt at the bottom. This voltage is negative enough at all points along the emitter-to-base junction, except near base 1, to prevent electron flow from the emitter through the base region to the collector. Near the bottom of the emitter PN junction, the forward bias between the emitter and base 1 will permit electrons to flow from emitter to collector. The effect of adding the high negative voltage on the other side of the base alters the electron flow of a normal NPN transistor. Effectively the size of the base region has been reduced and also the base resistance is reduced. Reducing the base region also reduces the active area of the base-to-collector junction, thus decreasing the collector capacitance. Decreasing the base resistance and collector capacitance improves the high frequency response of the transistor. The symbol for a tetrode transistor is shown in figure 9-6.

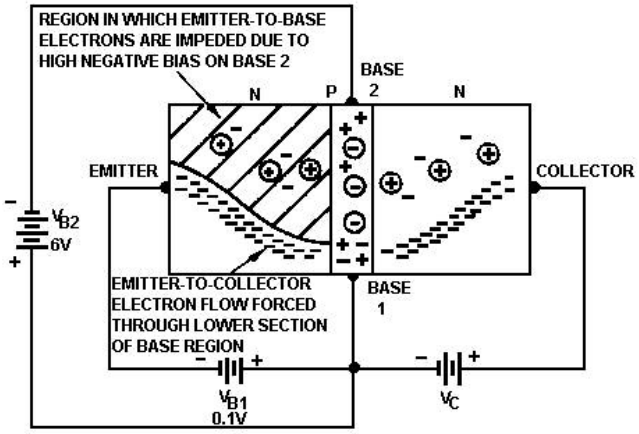


Figure 9-5. Tetrode transistor operation.

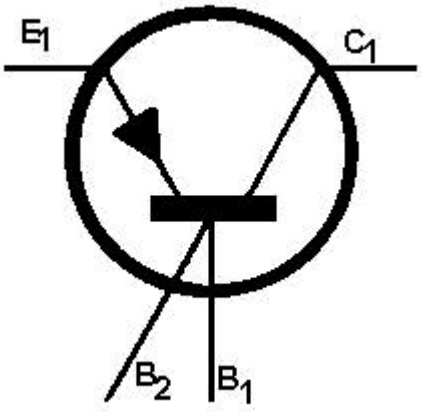


Figure 9-6. Tetrode transistor symbol.

e. Spacistor. The input and output capacitances of the conventional three-terminal junction transistor limit its high frequency amplification range. In addition, the transit time of current carriers from emitter to collector limits its high frequency response. In the conventional transistor, as the time of 1 cycle of the frequency to be amplified approaches the transit time, the gain falls off rapidly. The transit time becomes so long that current carriers in the base region diffuse (or migrate) from the emitter junction to the collector junction. Although physically limited, one method of reducing these effects is to reduce the size of the base region, resulting in what is called a spacistor. This method increases the response of transistors to approximately 75 mega Hertz. And by using other methods that involve nonuniform distribution of impurities in the base region, the response of transistors or spacistors can be increased to 350 mega Hertz.

(1) A, figure 9-7, shows a portion of the spacistor; this is a reverse-biased PN junction. Note that the depletion region in the N-type material is larger than that in the P-type material. This is accomplished by using a lower percentage of donor impurities in the N-type material than acceptor impurities in the P-type material. With the bias indicated, very little current flows through the junction. However, a strong electric field exists on either side of the junction. Because of the very short distance of the depletion region (several mils), a reverse bias of 100 volts will produce a substantial electric field of 60,000 to 120,000 volts per centimeter. This intense field is used to reduce the transit time.

(a) A connection, called the injector, is made to the upper depletion region (B, figure 9-7). The voltage of battery VII is less than that of battery Vc so that electrons flow from the injector to the collector. The transit time of electrons from the injector to the collector is very short because of the intense field through which the electrons flow.

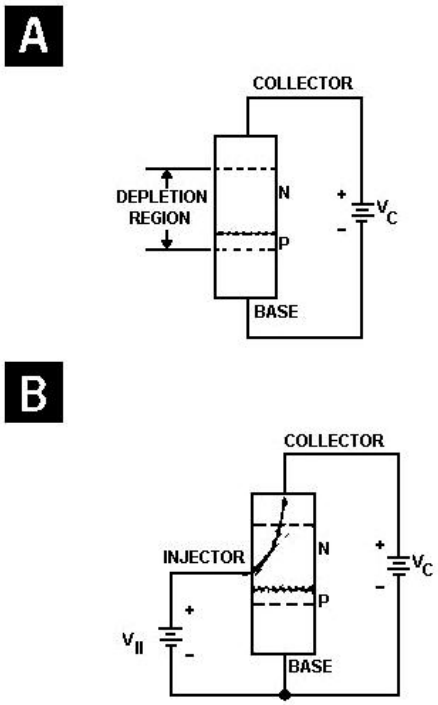


Figure 9-7a. Spacistor and spacistor amplifier.

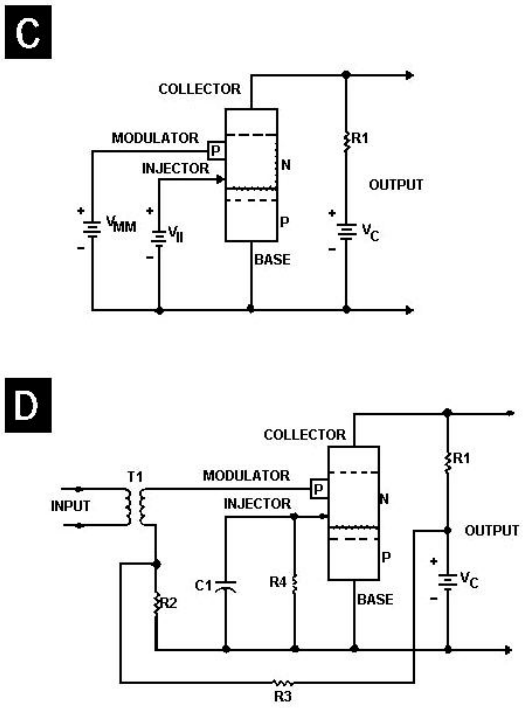


Figure 9-7b. Spacistor and spacistor amplifier.

(b) A second connection, called a modulator, is made to the depletion region on the same side of the junction and close to the injector (C, figure 9-7). The modulator is a small section of P-type material that forms a PN junction with the collector region. The voltage of battery VMM is less than that of battery Vc so that the PN junction formed by modulator and collector regions is reverse biased. This reverse biased PN junction produces a high input impedance at the modulator terminal. If battery voltage VMM is varied, the current flow between the injector and the collector varies accordingly. This effect indicates that the field between the modulator and the injector affects the injector current. Thus, a varying voltage (such as a sine wave) applied between the modulator and injector will result in a similarly varying current at the collector.

(2) A practical amplifier using the spacistor is shown in D, figure 9-7. A signal is coupled to the modulator terminal through transformer T1. The voltage divider, consisting of resistors R2 and R3, establishes the modulator bias. Resistor R4, bypassed by capacitor C1, provides the injector bias. Collector load resistor R1 develops the output signal.

f. Unijunction Transistor Operation. Since the invention of semiconductor diodes and transistors, experiments have led to the development of many different special purpose semiconductor devices. Unijunction transistors (UJT's) are really a type of diode. In fact, they are sometimes called double-base diodes, but they have some of the operating characteristics of transistors so they are usually called unijunction transistors. UJT's differ from ordinary junction diodes and transistors in physical construction, including where the external leads are attached to the semiconductor materials.

(1) Figure 9-8 is the standard symbol for the UJT. It is possible to see why it is sometimes called a double-base diode--it looks like a diode with two base leads. If the two base leads B1 and B2 are connected together, the UJT reacts like a junction diode too. Current will flow from base (B1, B2) to emitter but not from emitter to base because, like a junction diode, it has a low impedance to current flow in one direction and a high impedance in the other. In the UJT transistor terminology is used to identify parts (base, emitter) rather than diode terminology (cathode, anode).

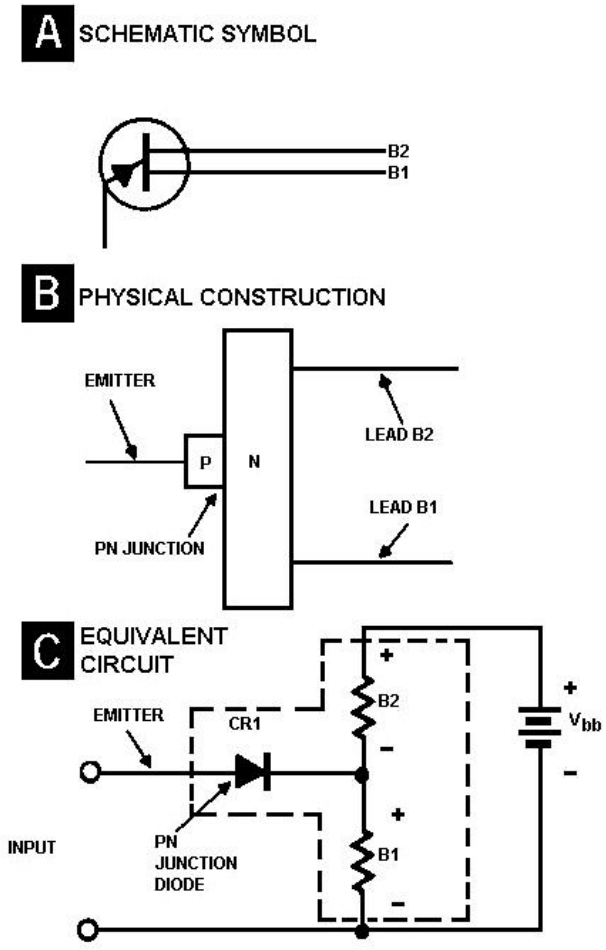


Figure 9-8. Unijunction transistor.

(2) B, figure 9-8, shows the physical construction of a UJT. To obtain the peculiar properties of UJT operation, the two base leads are connected to opposite ends of a bar of N-type semiconductor material. In practical use, a battery or power supply voltage is connected across this section (negative or ground on B1, positive on B2). A simple resistance is obtained between the base points. The total resistance normally has a value between 4,000 and 12,000 ohms depending on construction.

(3) A small section of P material called the emitter is joined to or fused into the bar of N material, usually somewhere near the mid-point region (B, figure 9-8). The emitter divides the total resistance and, as a result, the total voltage across B1-B2 into two parts (C, figure 9-8). A fraction of the total voltage appears between the emitter and B1 and the remainder between the emitter and B2. Where the emitter is attached determines the exact voltage between the emitter and B1. This placement of the emitter establishes the most important characteristic of the UJT--its conduction or switch-on point.

(4) If a positive voltage is applied to the emitter, the junction (shown as CR1 on C, figure 9-8) is reverse biased until the applied voltage is equal to the voltage on the opposite side of the junction. If the bias voltage is increased beyond this switch-on point, the junction is forward biased and the UJT conducts from B1 to the emitter. This is shown in figure 9-9. The emitter in this case shown connected to mid-point of the N material and the voltage at the junction is 20 volts since a 40-volt battery is used across B1-B2. Diode CR1 (the PN junction) is reverse biased until the applied bias voltage reaches +20 volts. As the bias voltage continues to increase, the junction is forward biased and current begins to flow through the base emitter junction. Current continues to flow at voltages above +20 volts.

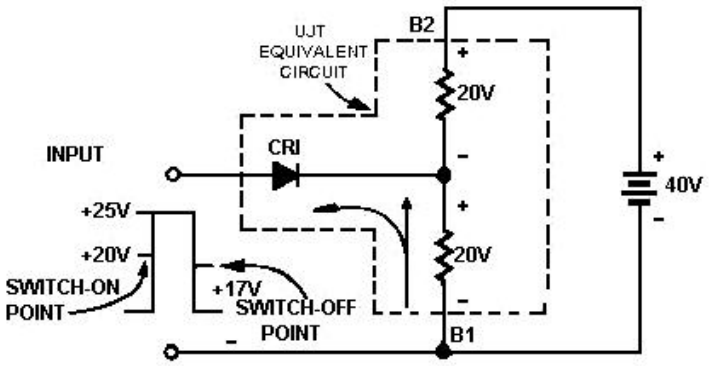


Figure 9-9. Conduction of unijunction transistor.

(5) When the bias is decreased to levels below +20 volts, the UJT continues to conduct until some lower critical voltage is reached; then it cuts off. This is the UJT's switch-off point. Conduction continues below the switch-on point because the potential barrier at the junction has been overcome and the current through the N material has decreased the effective resistance of the material. This is the UJT's negative resistance characteristic. It requires less voltage to maintain current through the diode than it does to establish the current initially. It should be noted that the increased current through B1 and resulting decreased resistance of B1 causes an increased current through B2 as well.

g. Four-Layer Diode

(1) Operation. The four-layer diode, sometimes called a PNPN-type switch (A, figure 9-10), consists of four layers of semiconductor material. The four layers of N- and P-type materials form three PN junctions. When properly biased, the center PN junction is reverse biased and the outer PN junctions are forward biased. The emitter-base junction of a three-terminal transistor is always forward biased, and the collector-base junction is always reverse biased. The four-layer diode therefore can be analyzed as two separate junction transistors. The dashed line through the center of the PN material divides the four-layer diode into a PNP transistor and an NPN transistor. The PN junction of the PNP transistor (B, figure 9-10), connected to the positive side of battery VEE, is forward biased and is, therefore, the emitter-base junction. The remaining PN junction of the PNP transistor is reverse biased and is the collector-base junction. The PN junction of the NPN transistor, connected to the negative side of battery VEE, is forward biased and is the emitter-base junction. The base of the PNP transistor is connected directly to the collector of the NPN transistor. The collector of the PNP transistor is connected directly to the base of the NPN transistor. The schematic representation of the four-layer diode is shown in C of the figure. Proper biasing is obtained from battery VEE. The arrows represent electron flow.

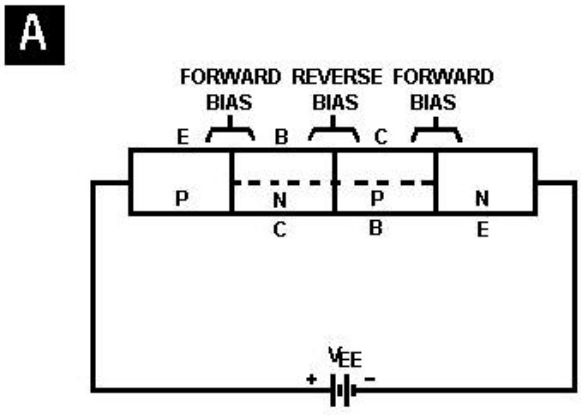


Figure 9-10a. Four-layer diode.

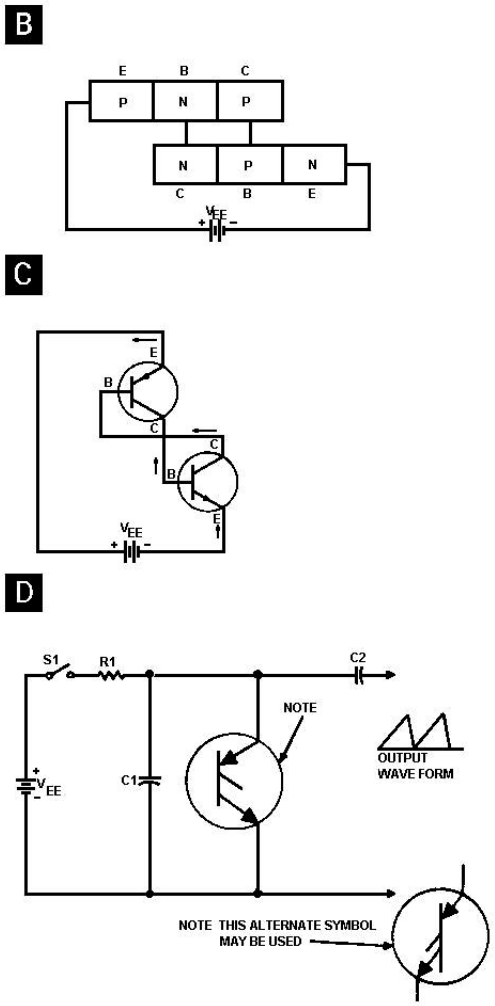


Figure 9-10b. Four-layer diode.

(2) Application. The schematic diagram of a sawtooth oscillator using the four-layer diode is shown in D, figure 9-10. Battery VEE furnishes power for the oscillator circuit. Switch S1 completes the circuit and applies power to the circuit. The time constant of resistor R1 and capacitor C1 determines the frequency of oscillation. The four-layer diode provides a discharge path for C1. When power is applied to the circuit through switch S1, C1 appears as a short circuit. Electrons flow through resistor R1 and capacitor C1 charges. When the voltage drop across C1 provides sufficient bias, the four-layer diode conducts. C1 then discharges rapidly through the four-layer diode. As C1 discharges, the bias applied to the four-layer diode decreases. When the bias reaches a minimum value for conduction, the four-layer diode stops conducting. Capacitor C1 again charges to a point where sufficient bias causes the four-layer diode to conduct. This sequence keeps repeating, and the output coupled through C2 is a sawtooth waveform.

h. Silicon Controlled Rectifier (SCR). The silicon controlled rectifier has many purposes and is especially useful as a rectifier, hence the name silicon controlled rectifier. An SCR is actually a rectifier only in the same sense that an ordinary junction diode is a rectifier. It passes current or allows current to flow in one direction but not in the other. The main differences between an SCR and a junction diode are the physical construction of each and a method of controlling the initial start of conduction by an SCR. An SCR is a four-layer diode that has a third connection called a gate (or gating) lead. The gate lead is connected to the P-type material next to the cathode as shown in figure 9-11.

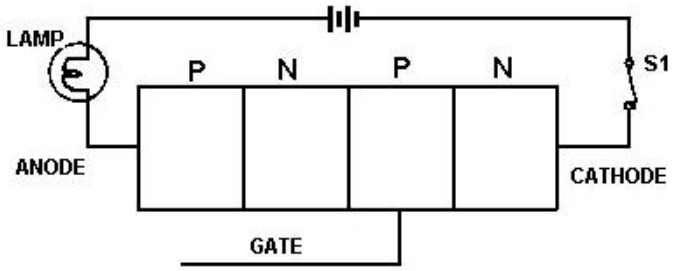


Figure 9-11. Construction of a silicon controlled rectifier.

(1) The function of an SCR in most applications is to offer a high forward-bias that prevents current from flowing when the bias voltage is applied, and to offer a low forward-bias when a positive voltage is applied to the gate lead. To provide these characteristics, the P and N materials must be less heavily doped--especially the materials on either side of the center junction. Less heavily doped materials result in a wide depletion region when they are joined together. This means an SCR does not conduct when the bias voltage is applied. The time of conduction is controlled completely by the gate lead.

(2) The diode in figure 9-11, for example, will not conduct when S1 is closed and as a result, the lamp is not normally on. However, if the gate lead is connected to a positive potential, electrons flow from the negative side of the battery or power supply, through the N material of the cathode toward the positive potential on the gate lead. The accelerated electrons pass through the wafer-thin P material and, having broken through the depletion region, continue moving toward the anode (P material) and the positive side of the battery or power supply. Once electrons start flowing, the potential barrier of the depletion region no longer exists and electrons will continue to flow even if the voltage on the gate lead is removed. The light will remain on until switch S1 is opened.

(3) The SCR, in this case, can replace a holding relay in a fault detector circuit. It can also be used as a remote controlled switch that couples signals through when a positive dc pulse is applied to the gate lead.

(4) A, figure 9-12, is a standard symbol for a silicon controlled rectifier. It is a diode symbol in a circle with the gate lead shown at the ctahode. An SCR, as it actually looks before it is mounted in a piece of equipment, is shown in B, figure 9-12.

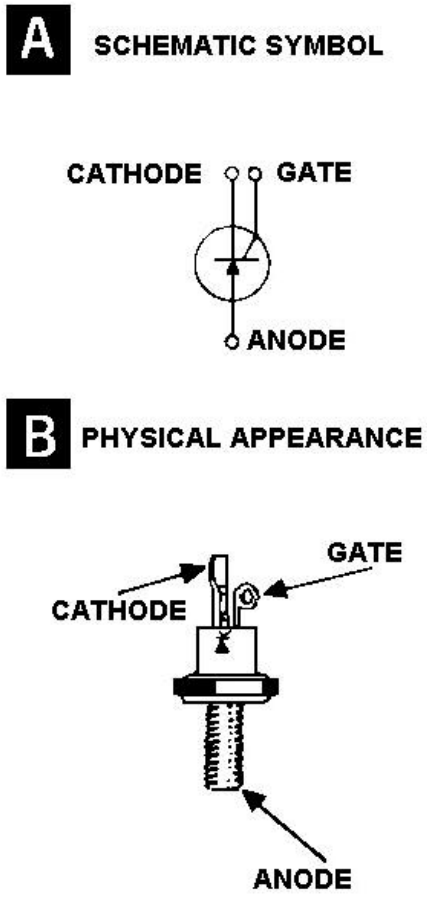


Figure 9-12. SCR symbol and appearance.

(5) In figure 9-13, the SCR is functioning as a controlled, half-wave rectifier. When the negative half-cycle of the input ac signal is applied to the cathode of the SCR, the diode is forward biased but does not conduct until a pulse is received from the voltage regulator. The regulator pulse gates the SCR into conduction and the remainder of the negative half-cycle is coupled through the SCR to the filter.

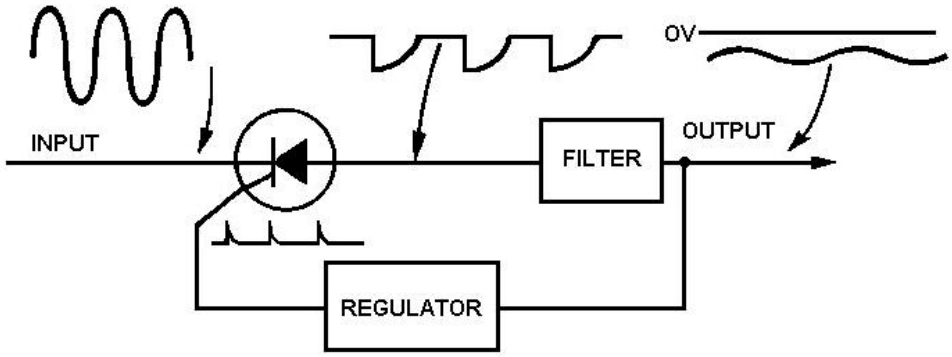


Figure 9-13. An SCR half-wave rectifier.

(a) The SCR stops conducting when electron flow reaches zero. As the positive half-cycle begins, the SCR is reverse biased and, like an ordinary diode, blocks any electron flow. Forward bias is reestablished by the start of the next negative half-cycle and the next pulse from the regulator gates the SCR into conduction again. Half-wave rectification is the result because only the negative half-cycle of the ac input is coupled to the filter.

(b) The gating pulses that trigger the SCR can occur earlier or later in each half cycle and thus control or regulate the output voltage. Since no electrons flow through the SCR until the gate pulse occurs, the output waveform and the resulting filtered output voltage will be determined by the timing of the gate pulse. If the pulse occurs late in the cycle as shown in A, figure 9-14, less of the cycle is gated to the output and the output voltage is low. If the pulse occurs early in the cycle as shown in B, figure 9-14, the SCR output is equal to almost the entire negative half-cycle and the output voltage is high.

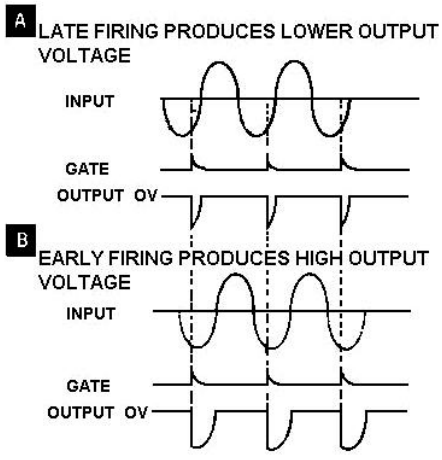


Figure 9-14. Gate pulse timing.

(c) Assume the power supply in figure 9-13 is adjusted manually for an output of -12v dc with a steady load applied. When connected to an operating circuit where load conditions change, the regulator detects any deviation from the -12 volt setting and adjusts the firing time of the SCR to compensate for the change. Changing gate pulse timing regulates the output. If the output voltage rises, the regulator shifts the gating pulse to occur slightly later in the cycle and reduces the output to -12 volts again. If the output voltage decreases, the regulator shifts the gating pulse to occur slightly earlier in the cycle and increases the output voltage to -12 volts again.

i. Field Effect Transistor (FET). The field effect transistor is sometimes called a unipolar transistor because only one type of carrier is employed. In other transistors, current flow results from the movement of both minority and majority current carriers (electrons and holes). The FET, however, is a majority current device; it depends primarily on electron movement in the N material or on hole movement in the P material. The FET has a very high input impedance and is used as an amplifier. Both NPN and PNP types are available.

(1) The FET may be compared to a garden hose with a pinching valve that controls the amount of water flowing through the hose. The three terminals may be called the source, the gate, and the drain: the source is where the water comes from (emitter); the gate is the control valve (base) and the drain is where the water leaves the hose (collector). A and B, figure 9-15, show a physical side and end view of the FET. This device is constructed by using a bar of silicon and making it either N type or P type by doping it. Then a contact is added to each end to connect the load and bias battery (C, figure 9-15). Finally, a section of either P or N type material is placed around the middle of the silicon bar and a variable reverse bias is applied to its contact (called the gate).

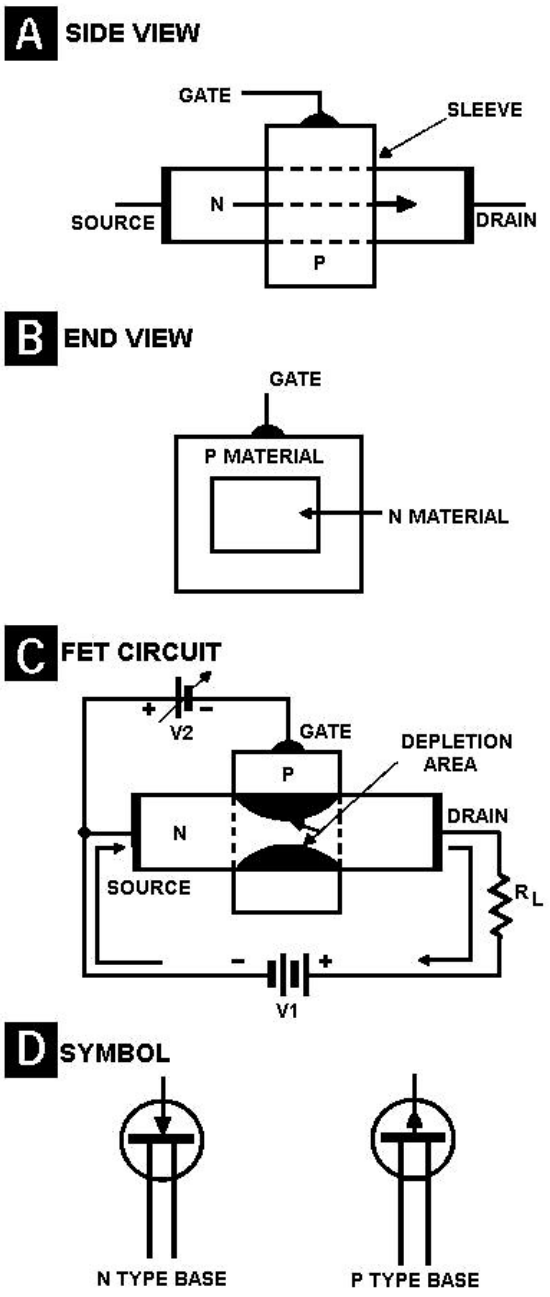


Figure 9-15. Field effect transistor.

(2) By varying the negative gate it is possible to vary the current between the source (emitter) and the drain (collector). If a load is placed in the output, variation of the gate voltage will cause variation in the load current and result in a varying voltage across the load resistor R1. The schematic symbols of the N type and P type FET are shown in D of the figure.

j. Tunnel Diode. A tunnel diode is a two-element semiconductor device similar to a conventional diode. The tunnel diode, however, has three distinct characteristics that make it electrically different from the conventional diode. Each of its three characteristics depend upon the value of bias voltage applied. Within a certain range of bias voltages, a tunnel diode has very low resistance in both directions (figure 9-16). Within a second range of bias voltages, it exhibits negative resistance; and, within the third range of bias voltages, it reacts as a conventional diode. The most important capability of the tunnel diode is its ability to amplify signals, which makes it comparable to a transistor.

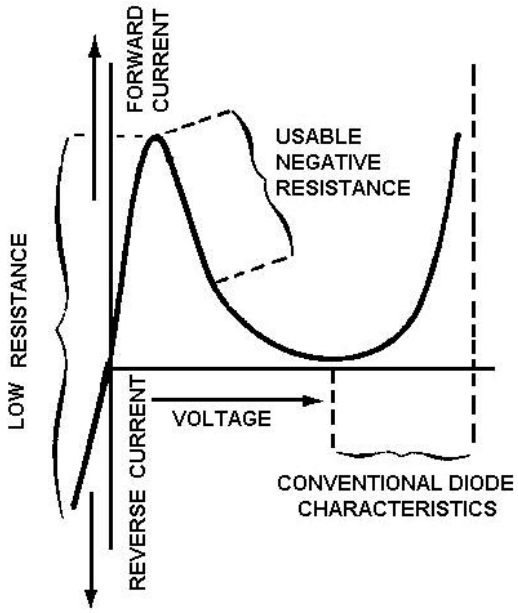


Figure 9-16. Tunnel diode characteristics.

(1) Doping of semiconductor diodes. When N- and P-type materials are joined to form a conventional semiconductor diode, a potential (sometimes called a potential barrier) develops at the junction. This potential generally ranges between 100 to 700 millivolts, depending upon the kind of semiconductor materials and the amount of doping. When a bias voltage is applied to the diode, it causes an electron flow (figure 9-17). The region in which the potential barrier exists is called the depletion region and the amount of doping controls the thickness of the depletion region. Conventional diodes have a thick depletion region (A, figure 9-18) as compared to the highly doped tunnel diode (B, figure 9-18).

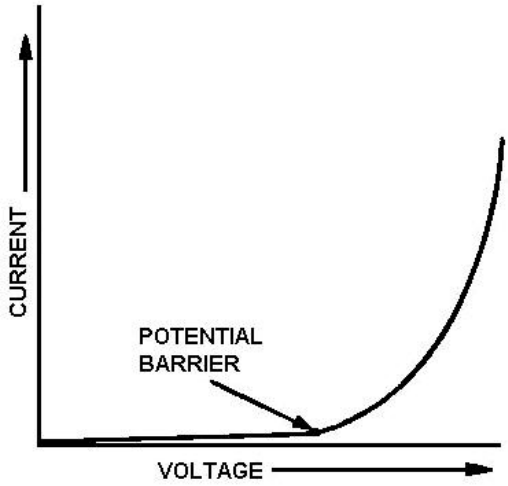


Figure 9-17. Conventional semiconductor diode characteristic curve.

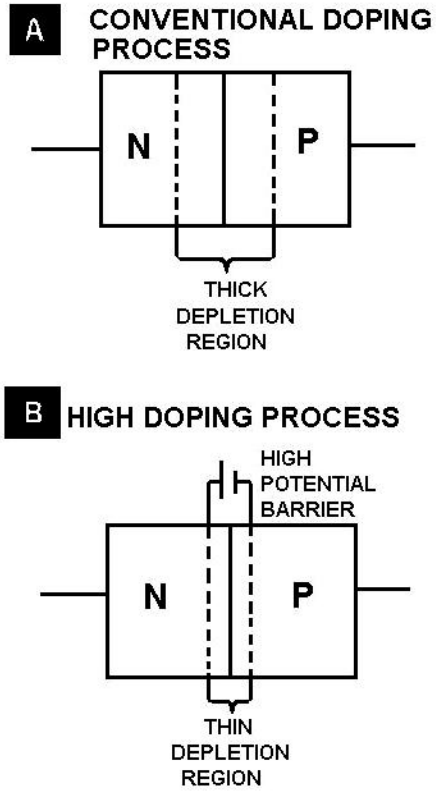


Figure 9-18. Effect of heavy doping upon the thickness of the depletion region.

(2) Tunneling. Heavy doping of the tunnel diode provides a greater number of free electrons in the N-type material and a greater number of holes in the P-type material. The thin depletion region at the junction is about 1/100 as thick as that of the conventional diode. Because the depletion region of a tunnel diode is very thin, the atoms of its two semiconductor materials continuously exchange electrons even before a bias voltage is applied. Electrons on either side of the junction cross the depletion region just as though it did not exist. The electron movement is an exchange of electrons that jump from one atomic orbit on one side of the junction, to another orbit on the other side of the junction. The net current from this exchange of electrons is zero, because exactly the same amount of exchange occurs in both directions.

(a) When a small value of positive bias is placed across the tunnel diode, the orbits of electrons in both the N-type and P-type materials are distorted in the direction of the positive bias potential (figure 9-19). The distorted orbits create a great attraction for free electrons, causing them to move from the N-type material to the P-type material. As an electron enters an orbit in the P-type material, it creates an imbalance among all of the orbiting electrons. This imbalance causes electrons at the far end of the P-type material to leave their orbits. The electrons near the positive terminal then enter the external conductor and are attracted to the positive voltage source. Electrons that enter the P-type material do not travel the entire distance through the P-type material. An electron entering at the junction and the exit of an electron at the far end occurs at the speed of light.

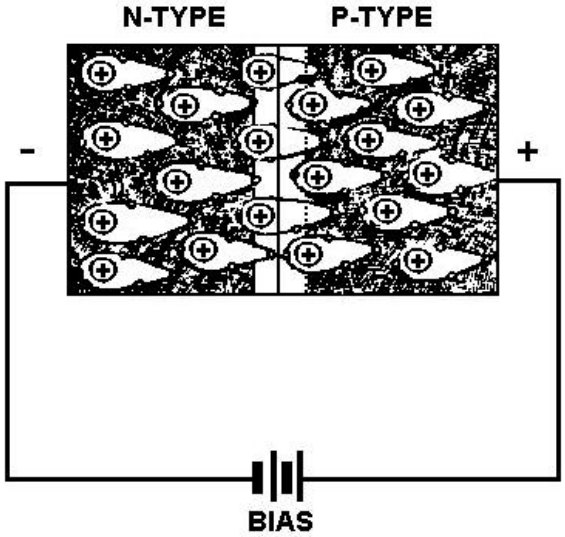


Figure 9-19. External voltage distorts electron orbits.

(b) As the bias voltage increases, more and more electrons move through the junction causing more and more tunnel current. However, when a certain bias voltage value is reached, the current starts to decrease. This action is shown by points A and B, figure 9-20. The distance between points A and B is called the negative resistance region. The reason that current decreases in this area is due to a reduction of electron-hole combinations at this energy level. A tunnel diode can be made to operate as a conventional diode if a high enough bias is applied that operates the diode beyond the negative resistance region.

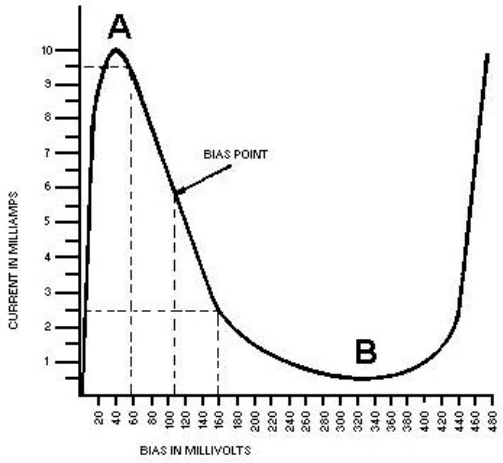


Figure 9-20. Operating region of a tunnel diode.

(3) Characteristic curve. Tunnel diodes amplify signals similar to a transistor. The characteristic curve in figure 9-20 shows that the tunnel diode is very sensitive to voltage changes in the negative resistance region (points A and B). A signal variation of 100 millivolts (from 60 to 160 mv) can cause a current change of seven milliamps (from 2.5 ma to 9.5 ma). Tunnel diodes may be used either as series connected or parallel connected amplifiers (figure 9-21).

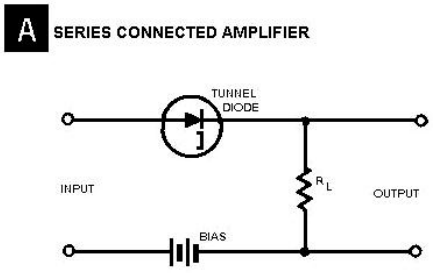


Figure 9-21a. Typical tunnel diode amplifier circuits.

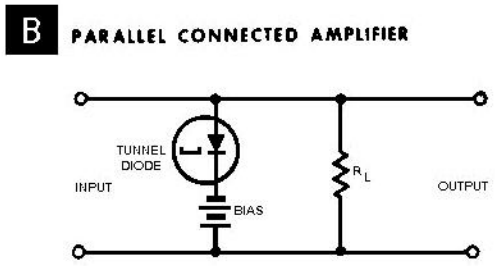


Figure 9-21b. Typical tunnel diode amplifier circuits.

2. INTEGRATED CIRCUIT MODULES.

a. General. An integrated circuit (IC) is so small that it takes up less space than a single transistor. Figure 9-22 shows the relative size of the transistor circuit and its IC replacement.

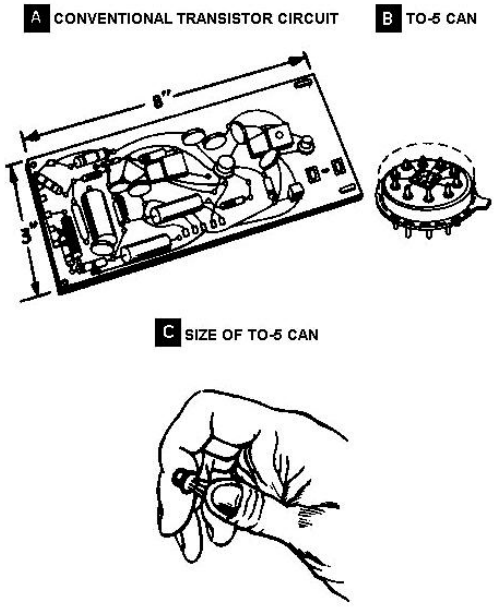


Figure 9-22. Comparison of the size of a transistor circuit and an IC.

(1) The IC may be a logic gate, an amplifier, or a combination of circuits that replace several transistors. The IC is made on a tiny chip of glasslike material, and is sealed in an airtight package. Examples of three types of IC packages are shown in figure 9-23.

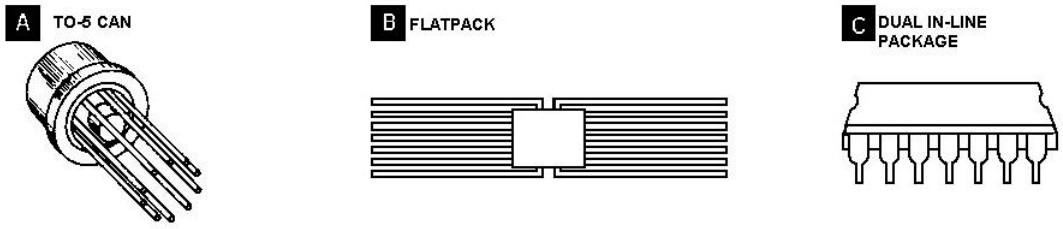


Figure 9-23. IC packages.

(2) IC's are used in electronic equipment not only because they reduce size and weight but also because they cost less, improve equipment performance, and are more reliable than the circuitry they replace. To reduce cost and size, transistors, resistors, and capacitors are built right into the IC. However, inductors, transformers, and large value capacitors must be mounted outside the IC package. There is nothing new about the way IC's operate. Electronic fundamentals apply to IC circuits just as they do to transistor circuits.

b. The Monolithic IC. The monolithic integrated circuit is the most widely used. It is called monolithic because the circuit is formed within a single semiconductor crystal. The circuit components are isolated from each other by reverse-biased PN junctions or by other methods. Monolithic IC's have good quality diodes and transistors, but poor average quality resistors and capacitors. The monolithic IC begins as a part of a very thin silicon wafer about 1-1/4 inch in diameter (figure 9-24). Each tiny square in this figure represents an IC. During production about 200 of these wafers are processed at the same time. The process used is an outgrowth of the technology developed to make silicon transistors. It includes epitaxial growth and oxidation, photomasking and etching, and diffusion.

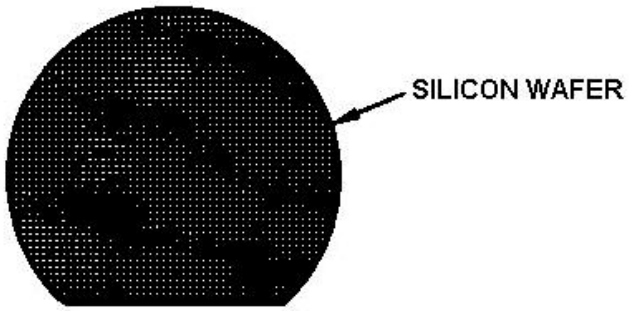


Figure 9-24. A silicon wafer.

(1) Epitaxial growth and oxidation. The term epitaxial growth refers to a process where one crystal layer is grown or formed on another crystal surface. The substrate or base material is either P-type silicon with the epitaxial layer N-type silicon, or the substrate is N-type silicon with the epitaxial layer P-type silicon. Using a chip of P-type silicon as a substrate lets show how a monolithic IC is made by epitaxial growth.

(a) The first step in making the IC is to grow an epitaxial layer of N-type silicon on the substrate. This layer is grown by heating the substrate to a high temperature in the presence of a gas containing hydrogen and a silicon compound (A, figure 9-25). The heat causes a chemical reaction between the hydrogen and the silicon compound that releases silicon atoms (Si). The free silicon atoms are attracted to the substrate and attach themselves to it to form the epitaxial layer. While this is going on, N-type impurity atoms are injected into the vapor causing the epitaxial layer to become N-type silicon (B, figure 9-25).

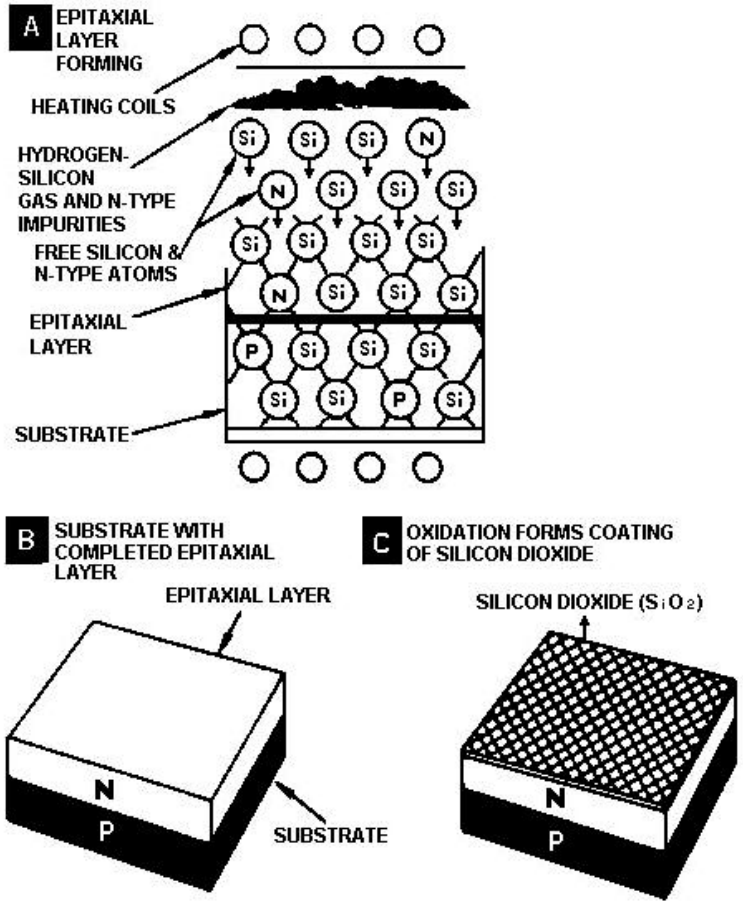


Figure 9-25. Expitaxial growth and oxidation.

(b) After epitaxial growth is completed, the chip is heated and exposed to wet oxygen gas or steam. The gas causes a protective silicon dioxide (Si02) coating to form on it (C, figure 9-25). This step is called oxidation.

(2) Photomasking and etching. Photomasking and etching are used to remove the SiO2 from selected areas on the chip. This step in the process allows circuit components and connections to be made in the epitaxial layer.

(a) First, the chip is coated with a solution called photoresist (A, figure 9-26). This is a solution that will not dissolve in photodeveloping fluid after it has been exposed to ultraviolet light. After the photoresist dries, a glass slide called a photomask is aligned on the chip. The photomask contains light and dark areas and is similar to a photo negative. Its purpose is to prevent the ultraviolet light from hitting these parts of the chip where it is desired to remove the SiO2. The chip is exposed to ultraviolet light (B, figure 9-26), and then washed with a photodeveloping fluid to dissolve the photoresist that was under the dark areas of the photomask. After this procedure only two patches of protective photoresist remain on the chip (C, figure 9-26).

(b) The uncovered SiO2 must be removed by etching to reach the epitaxial layer beneath. Etching means that the chip is placed in an acid bath to remove the bare SiO2 without affecting the epitaxial layer or the SiO2 in the two areas where the protective photoresist remains (D, figure 9-26). After etching, the remaining photoresist is stripped from the chip (E, figure 9-26).

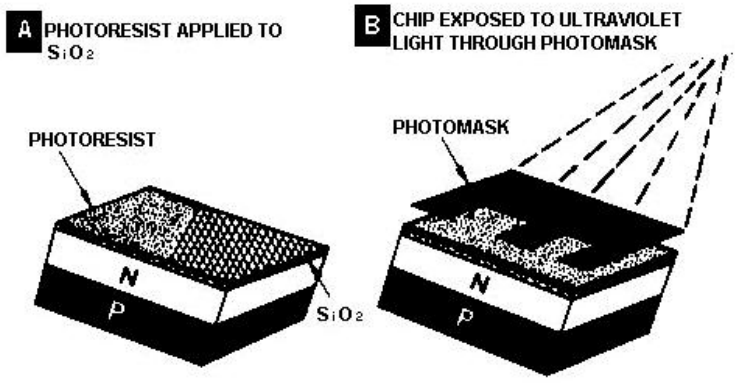


Figure 9-26a. Photo masking and etching.

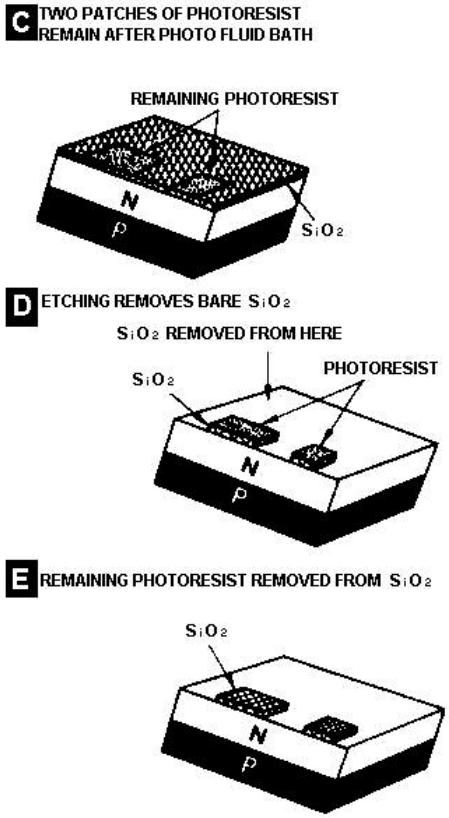


Figure 9-26b. Photo masking and etching.

(3) Diffusion isolates two N-type areas. Diffusion is a process in which different types of molecules intermix. For example, if drops of black ink are put in a glass of clear water (A, figure 9-27), they immediately begin to diffuse or mix with the water (B, figure 9-27). If given enough time, the concentration of ink molecules becomes uniform throughout the glass (C, figure 9-27). Diffusion can be speeded up considerably by heating or stirring the liquid.

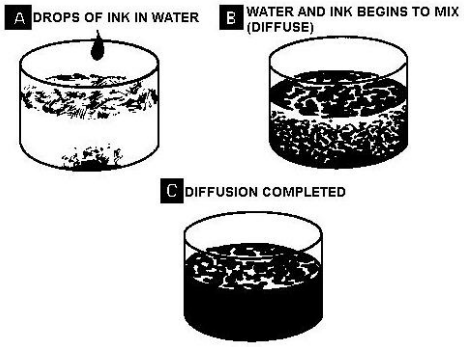


Figure 9-27. Diffusion of ink in water.

(a) Diffusion can also take place in a solid. This is the principle that allows isolation of the two N-type areas on the chip. To do this, the masked and etched chip (A, figure 9-28) is placed in a furnace that contains a precise number of P-type impurity atoms. The furnace is then heated to about 1,200 degrees C, causing the P-type atoms to diffuse down into the N-type epitaxial layer (B, figure 9-28). The diffusion process is rigidly controlled so that it can be stopped when the impurity atoms reach the original P-type substrate.

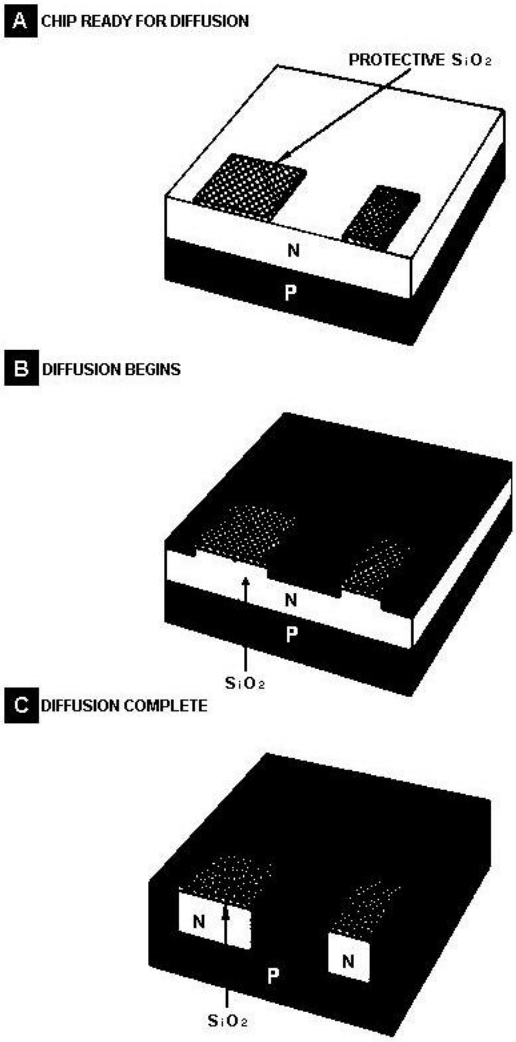


Figure 9-28. Isolation diffusion.

(b) Notice, in C, figure 9-28, that diffusion does not affect the N-type silicon directly below the protective SiO2. The two areas are isolated from each other. That's why it's called isolation diffusion.

(c) Figure 9-29 shows how the basic processes are repeated to complete the transformation of the chip into an IC. As many as 40 different steps may be required to complete an IC.

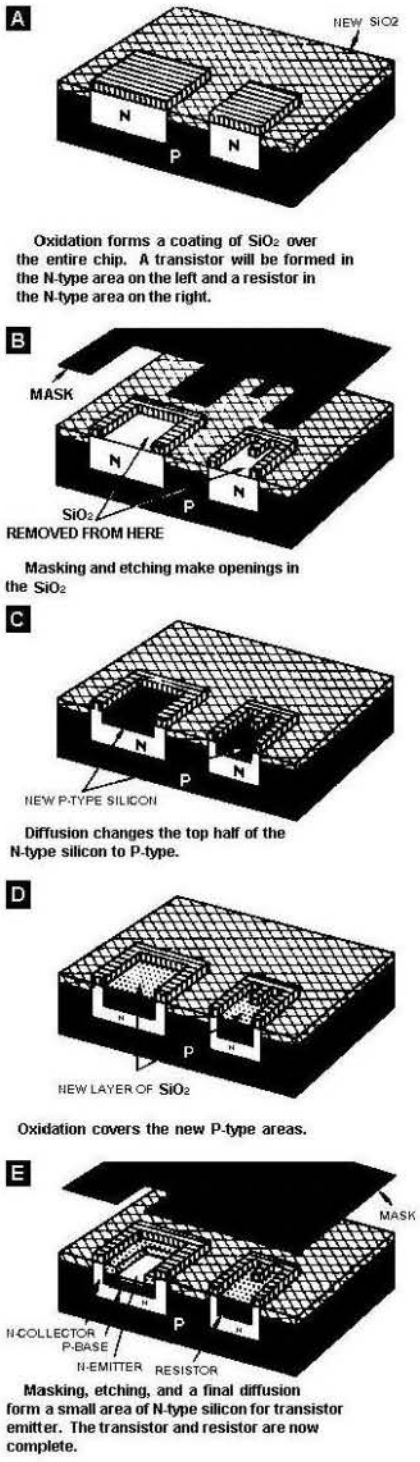


Figure 9-29a. Completing the IC (Sheet 1).

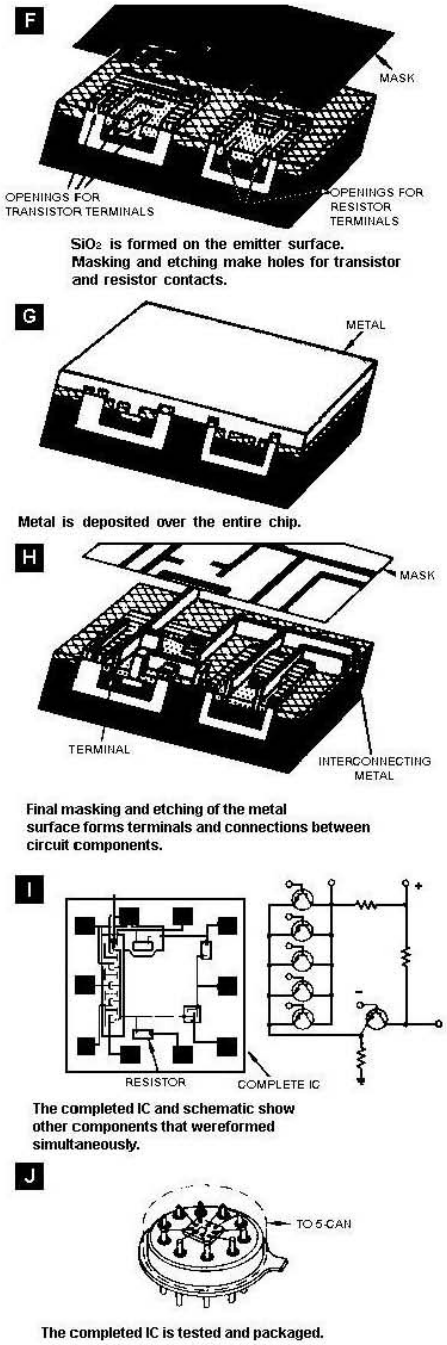


Figure 9-29b. Completing the IC (Sheet 2).

c. The Thin Film IC. Another type of integrated circuit, called a thin film IC, is made by depositing extremely thin films of metals and insulators on a glass or ceramic substrate. In this case, the substrate merely serves as a platform for the circuit, as opposed to the monolithic IC which is formed within the substrate.

(1) One method used to deposit thin films is vacuum evaporation (figure 9-30). A small piece of metal is placed inside a container. Directly above the metal is a substrate with a mask attached. The mask, similar to the ones used for monolithic IC's, will determine the pattern of the deposited film. After everything is in place, a high vacuum is created in the container and the metal is heated to its boiling point. As the metal boils, its vapor condenses on the substrate through the openings in the mask. This process is repeated with different materials and masks until all the required resistors, capacitors, and conductors are formed. If diodes or transistors are needed, miniature ones are attached to the circuit. Figure 9-31 is an exploded view of a thin film IC. If capacitors are required in this circuit, they are deposited as a separate film.

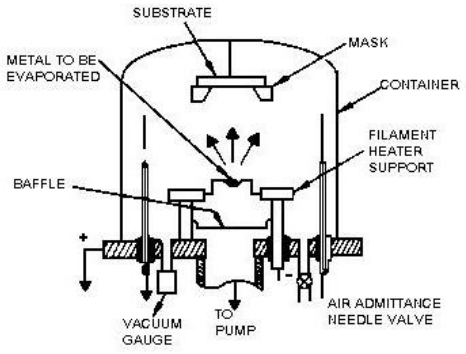


Figure 9-30. Vacuum evaporation forming a thin film IC.

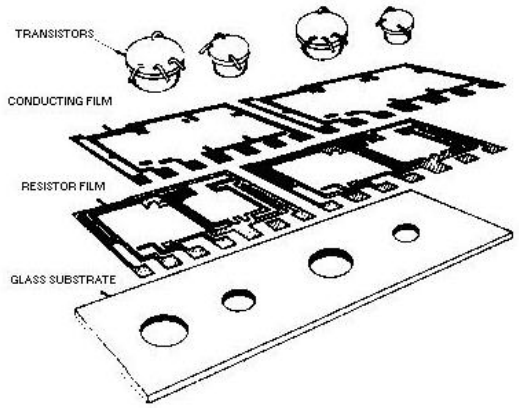


Figure 9-31. An exploded view of a thin film IC.

(2) In the thin film process it is possible to make resistors and capacitors with higher values and closer tolerances than those found in monolithic IC's. Thin film IC's are preferred for high frequency circuits and circuits that require precision components.

d. The Hybrid IC. The monolithic and thin film processes are sometimes combined to make a hybrid IC. The resulting hybrid can have the high quality diodes and transistors formed in the monolithic process, and the high quality resistors and capacitors formed in the thin film process. Hybrid IC's are also made by mounting individual chips, connected by fine wires, in the same package (figure 9-32). This method (called chip and wire) allows for more complicated circuitry and improves isolation between components.

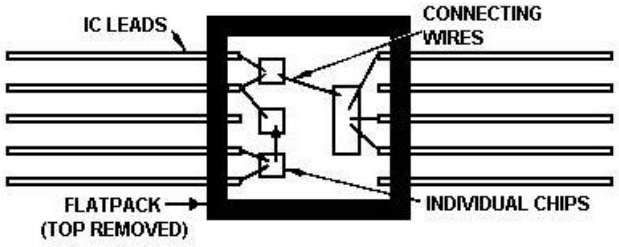


Figure 9-32. A chip and wire hybrid IC.

e. IC Applications. Ever since they were developed in 1960, more and more uses are being discovered for integrated circuits. Originally conceived for military equipment, IC's are now also being used in commercial products ranging from automobiles to hearing aids. IC's are divided into two categories-linear and digital. Linear IC's (also called analog IC's) produce outputs directly proportional to their inputs; they are used for transmitter and receiver circuits. Linear IC's are used for amplifiers (audio, video, RF, and IF), squelch circuits, mixers, oscillators, and other linear circuit functions. Most linear IC's have to be custom-made because the requirements of each circuit are usually different. Digital IC's perform switching functions in logic circuits.

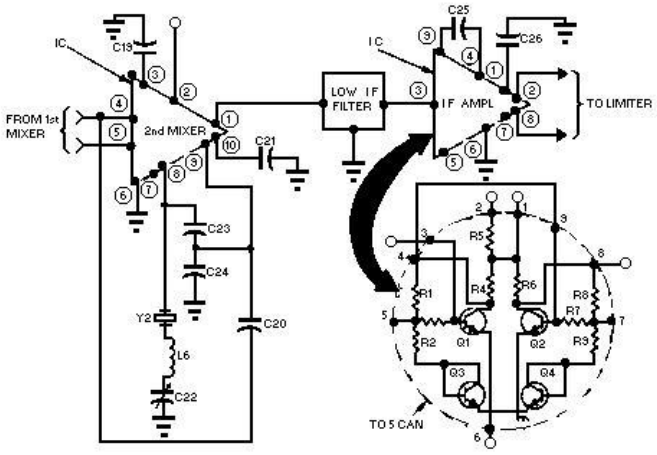


Figure 9-33. Linear IC's in a schematic diagram.

(1) Figure 9-33 shows a partial schematic of a radio receiver that uses linear IC's. The IC's are represented by triangles; the lines extending from them represent the leads to the IC package. In the blown-up portion of the figure, the detailed schematic for the IF amplifier is shown. Although the IF amplifier contains 13 different components, it takes up no more space than a conventional transistor. Because of this and the fact IC's need so little power to operate, some of the larger communications systems of today will be reduced to man-pack size in the future (figure 9-34).

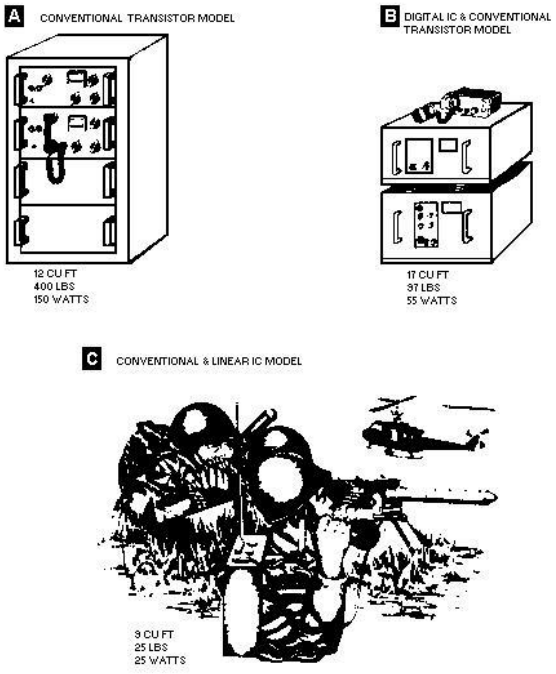


Figure 9-34. How IC's reduce the size of a communication system.

(2) Digital circuits have proved ideal for IC's because they operate with low power, are used thousands of times in the same form, and can operate effectively in spite of loose tolerances. Digital IC's include logic gates, flip-flops, counters, and shift registers. One example of a digital IC is the eight-input logic gate shown in figure 9-35. It is contained in a single monolithic chip and is used in high-speed computers.

(3) One big advantage that digital IC's have over conventional digital circuits is that they operate faster. That's because the components are microscopic and have no long leads between them. Some digital IC's can operate in 400 trillionths of a second. That's about the time it takes a beam of light to travel 5 inches.

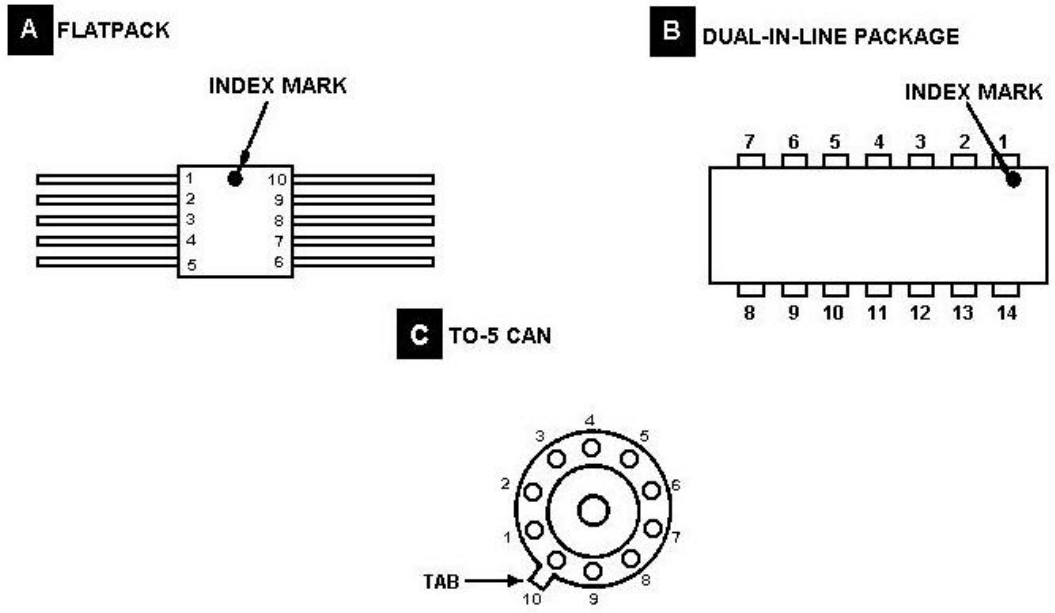


Figure 9-35. IC version of an eight-input logic gate.

f. Maintenance of IC's. Maintenance of IC's are based on a throw away policy. When an IC is defective, it is thrown away. The only problem is to make a determination of which IC is bad. In some cases the equipment itself will automatically pinpoint the defective IC. But if such sophisticated equipment is not available, the circuit will have to be fault isolated manually.

(1) Troubleshooting procedures for equipment with integrated circuits are somewhat different from the procedures used for conventional circuits. With conventional circuits, the circuit must be analyzed, various tests must be made to determine the defective component, and then the defective component is replaced. With an IC, the defective component cannot be replaced even if it has been identified. Instead of circuit analysis, the overall function of the IC must be known so that it may be determined if the IC is doing its job.

(2) Only the authorized maintenance and repair tasks, listed in the equipment manual, may be performed. Further, it's very important that only the test and repair equipment listed in the manual is used.

(3) Troubleshooting a suspected IC starts with checking its output. If the output signal indicates that something is wrong, then a check is made to find if the correct voltages are being applied to each pin. Next a check for open circuits between the circuit board terminals and the IC leads, is made. If the trouble is still not isolated, the external components connected to the IC are checked for proper operation. If the external components check out satisfactorily, the IC is replaced.

(4) When replacing an IC, remember these important points:

(a) Don't remove an IC until all external components are checked.

(b) Don't unsolder or change any IC lead while equipment is in the ON condition.

(c) Handle an IC with care to avoid damaging a lead.

(d) Use a thermostatically controlled soldering iron.

(e) Make sure the correct pins are soldered to the correct terminals. Figure 9-36 shows how the pins are numbered.

(f) Check all soldered terminals to see if they are good or bad.

(g) After soldering in a new IC, check all IC terminal voltages.

(h) When making voltage checks on connections, care must be taken to avoid shorting two terminals.

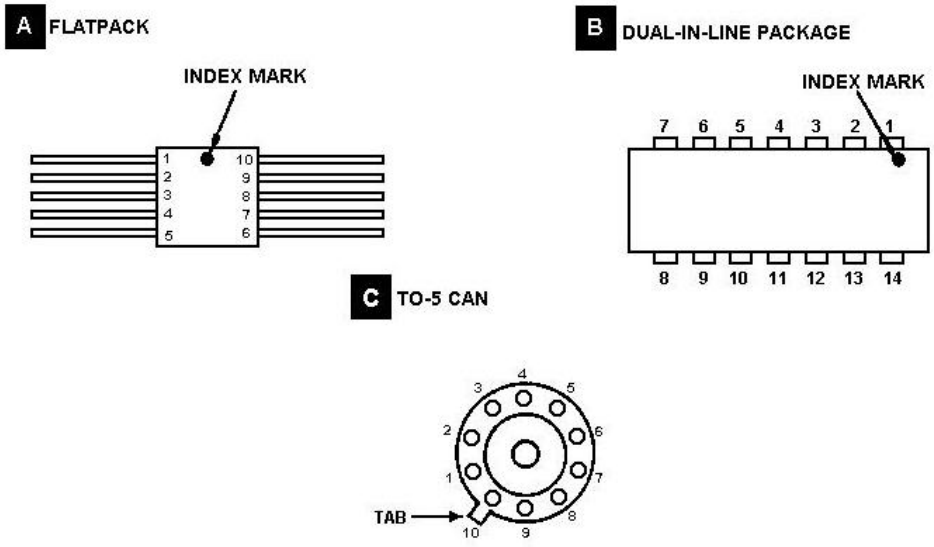


Figure 9-36. IC pin numbering.

MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS

EXERCISES FOR LESSON 9

1. The spacing between the cat whisker contact points of a point-contact transistor is one of the factors that controls the

   A. power output.
   B. frequency response.
   C. negative resistance.
   D. degree of saturation.

2. When light is concentrated upon the sensitive area of a single-junction photosensitive semiconductor, the PN junction of the device exhibits the property of

   A. generating a voltage.
   B. conducting a greater current.
   C. increasing its junction capacitance.
   D. emitting a light of amplified intensity.

3. Describe the action that takes place when light is applied to a double-junction photosensitive semiconductor.

   A. The light striking both junctions generates a voltage in each
   B. The light striking both junctions reduces the resistance of each
   C. The light striking one of the junctions results in a junction current which is amplified by the other junction
   D. The light striking one of the junctions results in a junction current which causes an amplified light to be emitted from the other junction

4. What type of transistor has a fourth terminal connected to the base region on the side opposite the normal base connection?

   A. Silicon-controlled rectifier
   B. Point contact transistor
   C. Tetrode transistor
   D. Spacistor

5. What is the prime advantage of the spacistor?

   A. Greater amplification
   B. Decreased noise
   C. Durability
   D. Higher frequency response

6. How is a conventional transistor converted into a spacistor?

   A. Reduce the size of the base region
   B. Increase forward bias
   C. Decrease size of the collector region
   D. Increase the size of the base region

7. In figure 9-9, part C, when battery Vbb is 60 volts, what voltage at the emitter will forward bias the UJT and cause current to flow?

   A. 10
   B. 20
   C. 30
   D. 40

8. How many PN junctions are formed in the four-layer diode pictured in D of figure 9-10?

   A. 1
   B. 2
   C. 3
   D. 4

9. What is the purpose of the gate lead in an SCR?

   A. To provide a starting and stopping voltage to allow the SCR to offer a high-forward bias
   B. To allow the SCR to conduct by offering the SCR a low-forward bias
   C. Present the SCR with a low reverse bias when starting
   D. Gate only fixed outputs when a high negative pulse is present at the gate lead

10. When is the SCR shown in figure 9-13 cut off during normal operation?

   A. Whenever the gate pulse is removed
   B. When the input goes negative
   C. When the input goes positive
   D. Only during the presence of a positive pulse on the gating lead

11. What type of transistor is a majority current device?

A. Tunnel diode
B. SCR
C. Spacistor
D. FET

12. Refer to C of figure 9-15. What parts of the FET represent the base, emitter, and collector?

	Collector	Base	Emitter
A.	Source	gate	drain
B.	Drain	source	gate
C.	Drain	gate	source
D.	Gate	drain	source

13. What is the region between A and B of figure 9-20 called?

A. Negative resistance
B. Barrier
C. Low resistance
D. Maximum bias

14. Which is NOT a characteristic of a tunnel diode?

A. At certain bias voltages the diode has a very low resistance in both directions
B. At certain bias voltages the diode reacts as a conventional diode
C. With proper bias voltages the diode exhibits negative resistance
D. With proper bias voltages the diode exhibits a high positive resistance

15. Which component is usually not built into an integrated circuit package?

A. Resistor
B. Inductor
C. Capacitor
D. Transistor

16. When one crystal layer is grown or formed on another crystal surface this is known as

A. etching.
B. diffusion.
C. epitaxial growth.
D. photomasking.

17. When manufacturing a thin film IC, what is the relationship of the substrate with the circuit?

A. Acts as a conductor within the circuit
B. Acts as a platform for the circuit
C. Does not come in contact with the circuit
D. Melted and diffused within the circuit

18. During the process of isolation diffusion, what prevents the mixing of the N type and P type material?

A. Rigidly controlled by heat
B. SiO2 protective covering
C. Inability of a solid to absorb foreign impurities
D. Controlled application by pressure and heat

19. What is the basic maintenance policy in regard to IC's?

A. Throw away
B. Evacuate to an IC repair shop
C. Troubleshoot and replace defective components
D. Repair with special tools including thermostatically controlled soldering iron

20. What is NOT a reason for using IC's in digital computer circuits?

A. Small size
B. Use low power
C. Operate at high speed
D. Easily repairable

MMS SUBCOURSE NUMBER 701, TRANSISTORS AND SEMICONDUCTORS

APPROVED SOLUTION

LESSON 1

Introduction to Transistors and Semiconductors

1.	B	(para 1)	6.	C	(para 3)
2.	C	(para 2a)	7.	B	(para 6)
3.	A	(para 2b)	8.	D	(para 4, 5b)
4.	D	(para 2b)	9.	A	(para 5c)
5.	B	(para 2e)	10.	B	(para 7)

LESSON 2

Theory of Transistors and Semiconductors

1.	D	(para 1b(1)(b))	11.	B	(para 2a(2))
2.	D	(figure 2-1)	12.	C	(para 2a(6))
3.	B	(para 2b(1)(a)1)	13.	D	(figure 2-1)
4.	C	(para 1b(1)(a)3)	14.	C	(para 1f(1))
5.	A	(para 1e(2)(a)(b))	15.	D	(para 2d(2))
6.	C	(para 1d)	16.	A	(figure 2-13)
7.	B	(para 2f(4))	17.	D	(para 2a(3))
8.	B	(para 1g(1))	18.	C	(para 2e)
9.	B	(para 1h)	19.	B	(para 3b(2))
10.	C	(para 1h(4))	20.	A	(para 3c(3))

LESSON 3

Semiconductor Diode Rectifiers and Transistor Amplifier Fundamentals

1.	D	(para 1a(1))	11.	C	(para 2d(1))
2.	B	(para 1a(1))	12.	B	(para 1e(1))
3.	C	(para 1a(2))	13.	A	(para 4)
4.	B	(figure 3-5)	14.	D	(para 5)
5.	A	(para 1b(4))	15.	C	(para 6)
6.	B	(para 1f(2))	16.	D	(para 6)
7.	B	(para 1e)	17.	A	(para 6)
8.	C	(para 1d)	18.	C	(para 7)
9.	B	(para 1d(1))	19.	A	(para 8)
10.	A	(para 2c)	20.	A	(para 8a)

LESSON 4

Bias Stabilization

1.	B	(para 1a(1))	9.	C	(para 2b(1)
2.	C	(para 1a(2))	10.	A	(para 1b)
3.	C	(para 2a)	11.	C	(para 3b)
4.	A	(para 2b(2))	12.	D	(para 3d)
5.	A	(para 3a)	13.	C	(para 5b)
6.	B	(para 3c)	14.	B	(para 4c)
7.	D	(para 4a)	15.	C	(para 4b)
8.	A	(para 5a)			

LESSON 5

Transistor Amplifiers

1.	C	(para 1b(4))	11.	B	(para 4a(3))
2.	D	(para 2b(3))	12.	A	(para 4c(4))
3.	B	(para 2c)	13.	A	(para 4c(2))
4.	B	(para 2c(1))	14.	D	(para 4d(1))
5.	C	(para 1b(2))	15.	A	(para 4d(2))
6.	D	(para 2e)	16.	C	(para 4f(1))
7.	C	(para 2f(3))	17.	D	(para 4f)
8.	D	(para 3c(2))	18.	B	(para 5c(1))
9.	B	(para 3d(2))	19.	C	(para 5c(4))
10.	A	(para 3c(4))	20.	C	(para 5d(2)(a))

LESSON 6

Oscillators and Multivibrators

1.	D	(para 1c)	14.	C	(para 2a(1)(c))
2.	B	(para 1a(2))	15.	B	(para 2b(3))
3.	B	(para 1b(3))	16.	A	(para 3a(1))
4.	A	(para 1c(1))	17.	D	(para 3b)
5.	C	(para 1c(3))	18.	C	(para 3a(2)
6.	D	(para 1d(1))	19.	A	(figure 6-21)
7.	D	(para 1e)	20.	D	(para 3b(4))
8.	C	(para 1e(1))	21.	B	(para 3c)
9.	B	(para 1h(1))	22.	D	(para 3c(2)(a))
10.	C	(para 1g)	23.	C	(para 3c(2)(b))
11.	A	(para 1f(2))	24.	B	(para 3d)
12.	B	(para 2a(3))	25.	B	(para 3d)
13.	C	(para 1i(1))			

LESSON 7

Triggered and Gating Circuits

1.	B	(para 1a(2)(c))	14.	A	(para 1n(1))
2.	D	(para 1b(1))	15.	C	(para 1n(2))
3.	C	(para 1c(2))	16.	D	(para 2a(1))
4.	C	(para 1d(1))	17.	C	(para 2b)
5.	C	(para 1e(2))	18.	B	(para 2b(2)(e))
6.	C	(para 1f(2))	19.	A	(para 2c(1)(a))
7.	A	(para 1g(3))	20.	C	(para 2c(2)(b))
8.	D	(para 1h(2))	21.	D	(para 2d(1)(a))
9.	B	(para 1j(1))	22.	B	(para 2d(2)(a))
10.	D	(para 1i(1))	23.	D	(para 2e(1))
11.	D	(para 1k)	24.	A	(para 2e(2)(a))
12.	C	(para 1l)	25.	C	(para 2e(3))
13.	B	(para 1m)			

LESSON 8

Modulation and Demodulation

1.	D	(para 1a)	9.	B	(para 2c)
2.	C	(para 1b)	10.	D	(para 2d(1)
3.	B	(para 1c(1)(b))	11.	B	(para 2d(a))
4.	D	(para 1d(1))	12.	A	(para 1d(2)(b))
5.	B	(para 1e(2)(a))	13.	C	(para 2b(2))
6.	C	(para 2a)	14.	A	(para 2c)
7.	A	(para 2a(1))	15.	D	(para 1a)
8.	C	(para 1b(1))			

LESSON 9

Special Purpose Semiconductor Devices

1.	B	(para 1b(5))	11.	D	(para 1i)
2.	B	(para 1c(3))	12.	C	(para 1i(1))
3.	C	(para 1c(3)(b))	13.	A	(para 1j(2)(b))
4.	C	(para 1d(1))	14.	D	(para 1j)
5.	D	(para 1e)	15.	B	(para 2a(2))
6.	A	(para 1e)	16.	C	(para 1b(1))
7.	C	(para 1f(4))	17.	B	(para2c)
8.	C	(para 1g(1)	18.	B	(para 2b(3)(a))
9.	B	(para 1h)	19.	A	(para 2f)
10.	C	(para 1h(5)(A))	20.	D	(para 2e(2))